Fundamentals of ELECTRICITY

RESTRICTED

NAVY TRAINING COURSES

FUNDAMENTALS OF ELECTRICITY

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PREFACE

This book was written for the enlisted men of Naval Aviation. It is one of a series of books designed to give them the information necessary to perform their aviation duties.

A knowledge of the fundamentals of electricity is of primary importance to Aviation Radiomen, Aviation Electrician's Mates, and Aviation Radio Technicians. But other rates and other specialists will find it valuable background for their work. It will prove an important adjunct to the study of electric turrets and bomb sights. It will be helpful in obtaining a better comprehension of ignition systems, certain engine accessories, electrically operated propellers and instruments.

Beginning with static electricity, this book presents a concise explanation of electronic theory and proceeds to the practical matters of circuits, Ohm's Law, batteries, magnetism, generators and motors. It concludes with the electrical applications found in sound apparatus.

As one of the NAVY TRAINING COURSES, this book represents the joint endeavor of the Naval Air Technical Training Command and the Training Division of the Bureau of Naval Personnel.

TABLE OF CONTENTS

CHAPTER 11

CHAPTER 12

CHAPTER 13

CHAPTER 14

CHAPTER 15

CHAPTER 16

FUNDAMENTALS OF ELECTRICITY

CHAPTER 1

WHAT IS ELECTRICITY?

STATIC ELECTRICITY

Have you ever noticed a girl combing her hair? It dances around, and some of it stands out, away from the rest. You hear a faint crackling sound. If it were dark, you would be able to see tiny sparks as the comb moves through her hair. ELECTRICITY! What is it? Where does it come from?

The girl—and you too—are electric. According to the modern theory of the structure of matter, ALL substances are made up of very small electric particles—ELECTRONS and PROTONS. Therefore, if all the electrons and protons were removed from your body, you would vanish. There would be no you.

Electrons and protons are said to be electrical simply because of the way they act. Thus, electrons gang up and make sparks when a girl runs

a comb through her hair. By the friction between comb and hair, she knocks electrons loose from her hair. And the comb picks up a load of these electrons.

The loss of electrons causes the hair to become electrically charged. And the increase causes the comb to become electrically charged. It works BOTH WAYS. Add electrons to a sample of matter, or take electrons away, and you build up a charge. Hence, a charged object is electrified either because it has an excess of electrons or because it has a shortage of electrons. Any matter containing equal numbers of electrons and protons is uncharged.

Then, why not add or remove protons in order to get a charge? It can't be done. Protons are almost 2,000 times as heavy as electrons and are more closely knit into the bedrock structure of matter. You would have to destroy a substance utterly before you could get at the protons.

Hold the charged comb near your girl's electrified hair and you'll see that strands are attracted. The charge caused by the extra electrons on the comb attracts the charge caused by the shortage of electrons on the hair. Because there is an excess of electrons in the one case and a shortage in the other, the two charges are known as UNLIKE charges UNLIKE CHARGES ATTRACT ONE ANOTHER.

What about like charges? You note that electrified strands of hair stand apart from one another. LIKE CHARGES REPEL ONE ANOTHER.

For no obvious reason, early scientists gave the name POSITIVE to charges such as those on your girl's hair and the name NEGATIVE to a charge such as that on the comb. Then, more recently, electrons and protons were discovered. So, in the light of this later knowledge, any

charge caused by a shortage of electrons is positive. And any charge built up by adding electrons is negative.

Note that charges of electricity are produced by friction between two DIFFERENT substances—comb and hair. Rub any two different substances together and you electrify both. When your girl runs across a carpet to you, a spark may leap from her to you—if you let her get close enough. Her soles pick up electrons from the carpet.

Such charges are known as STATIC ELECTRICITY, or electricity at rest. An ELECTRIC CURRENT is the flow of electrons along a wire. In the wire there are many FREE electrons—electrons free to move along from atom to atom.

ATOM

Suppose you could deal readily with particles so unimaginably tiny as electrons and protons. Take an electron and let it spin around a proton. What have you made? A tiny bit of hydrogen—an ATOM OF HYDROGEN—the smallest possible sample of this gas. If you split the atom, therefore, you have electric particles right back on your hands. You can see a diagram of a hydrogen atom in figure 1A.

The proton of the hydrogen atom is a positive charge, and therefore attracts and more or less permanently holds into the negatively charged electron, which circles about the proton much as the earth does around the sun. The central part of this atom or any other atom is known as the NUCLEUS. The hydrogen atom happens to have only one proton forming the nucleus. The oxygen atom has a more complicated central portion, or nucleus, with eight protons that attract and hold eight electrons circling around at tremen-

dous speed. See figure 1*B* for the structure of the oxygen atom. The nucleus of any atom is positively charged because of the protons concentrated there.

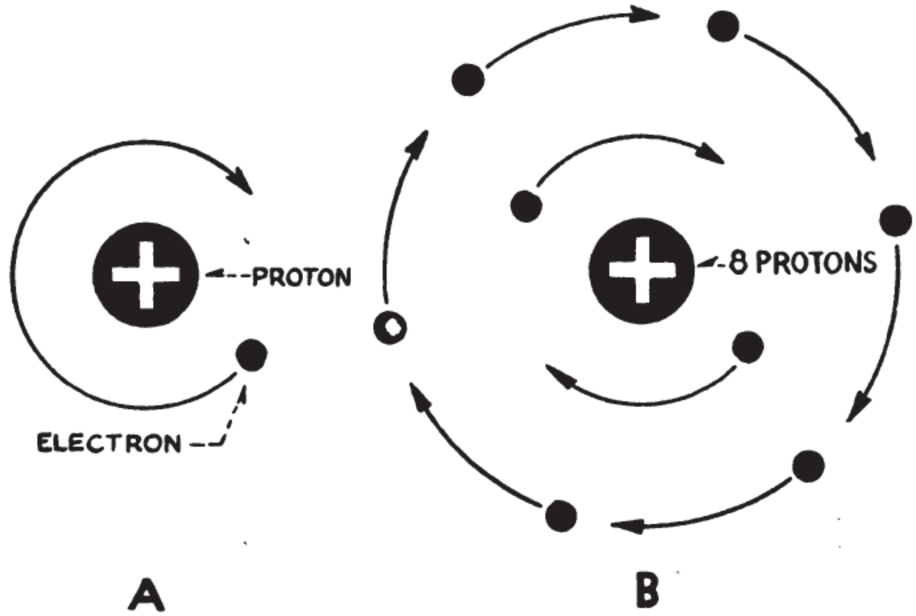


Figure 1.—Structure of hydrogen and oxygen atoms.

ELEMENT

Hydrogen is an element—that is, a simple substance made up of the same kind of atoms. Oxygen is an element. There are more than 90 elements—gold, silver, platinum, helium, chlorine, iodine, and so on—and each element has its own peculiar type of atom. And every atom has a positively charged nucleus with electrons revolving in orbits about it.

MOLECULE

You could mix hydrogen gas and oxygen gas and stir indefinitely—and you would still have a mixture of two gaseous elements. But introduce a spark, and there is an explosion. If you don't blow your head off, you would discover that water was produced by the reaction. Two hydro-

gen atoms combine with an oxygen atom to make a molecule of water, as you see in figure 2. A MOLECULE of a substance is the smallest possible particle which has the physical and chemical properties of the original substance. Crack a molecule of water and you don't get smaller particles of water. You get two atoms of hydrogen and one atom of oxygen. Molecules of other substances are built up in a similar way.

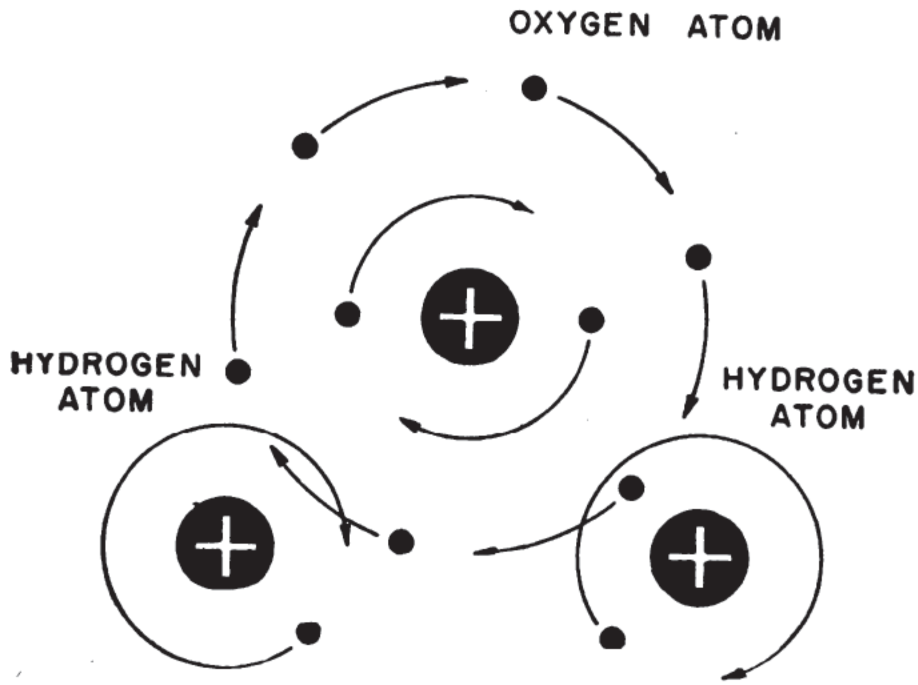


Figure 2.—A molecule of water.

In any substance, electrons can move about from molecule to molecule. They can move through metals with the greatest ease. METALS HAVE MANY FREE ELECTRONS. So metals are good CONDUCTORS, or carriers of electricity. Nonmetals are poor conductors, and offer great resistance to the movement of electrons. Glass, rubber, and oil are practically nonconductors, and hence are called INSULATORS.

Just as there are no perfect women, there are no perfect conductors or insulators. Every con-

ductor offers some resistance. Every insulator permits some flow of electrons. In the table below, certain materials are listed in the approximate order of their values as conductors and insulators.

CONDUCTORS	INSULATORS
Silver.	Dry air.
Copper.	Glass.
Aluminum.	Mica.
Brass.	Rubber.
Iron.	Asbestos.
Lead.	Bakelite.

THE LEYDEN JAR

Electrons may be trapped and piled up in a Leyden jar—a simple CONDENSER. This device consists of two conductors separated by an insulator. As you see in figure 3, a glass jar in-

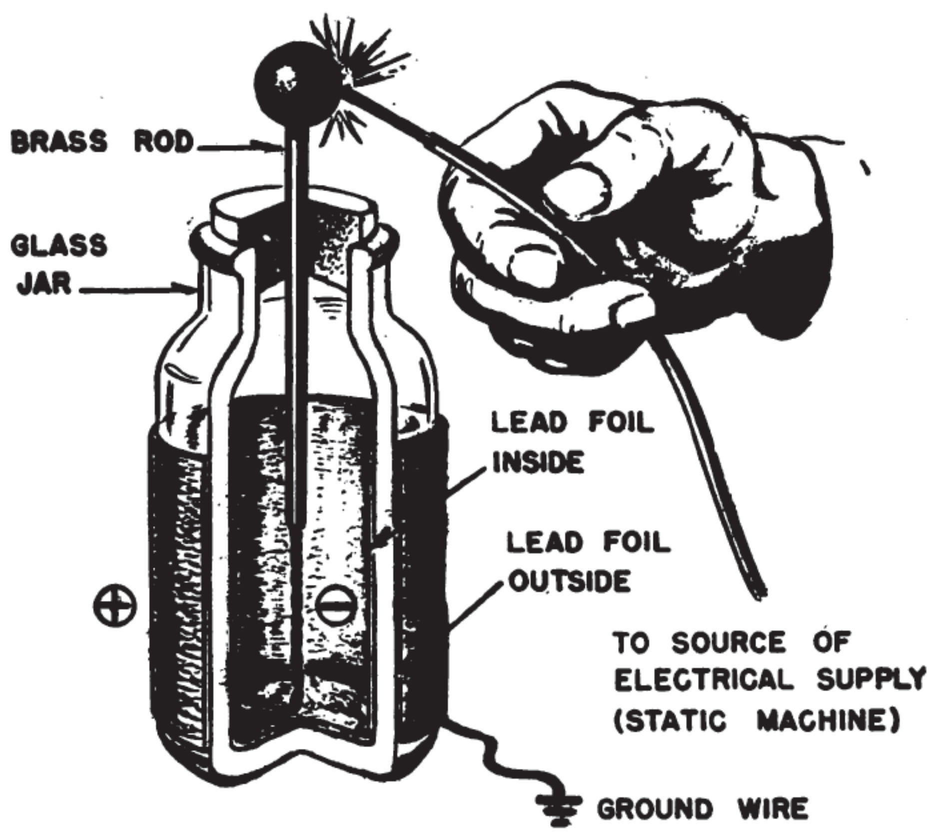


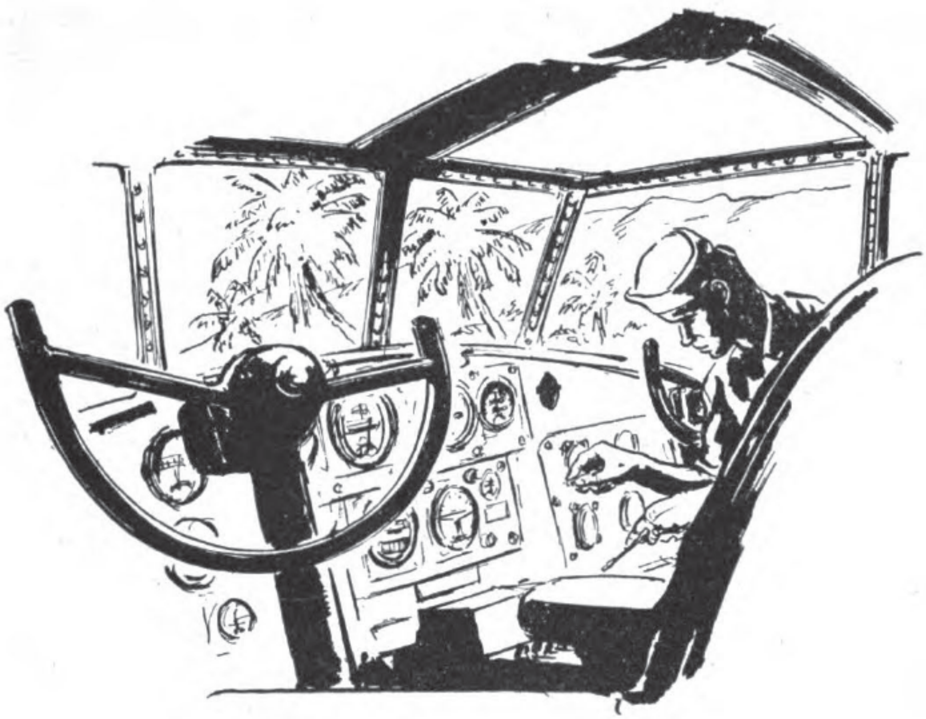
Figure 3.—Charging a Leyden jar.

sulator is partially coated with metallic foil, such as lead foil. This extends about half way up the jar, BOTH inside and outside. A knobbed brass rod runs down through an insulating stopper, usually wood, and is connected to the inside foil by means of a metal chain.

The first step in charging a Leyden jar is to GROUND the outside foil—that is, the outside foil is connected with the ground by means of a wire. Electrons can now readily race up from the earth to the outside foil, or from the outside foil down to the earth.

Electrons are put on the knob, rod, chain, and inside foil by touching a negatively charged body to the knob. If the knob is connected to an electrostatic machine which supplies a steady stream of electrons, a large charge can be concentrated in the jar. Electrons piling up on the inside foil repel electrons from the outside foil and force them down into the ground. If the outside foil is NOT grounded, only a tiny charge can be trapped in the jar—because the electrons on the outside foil cannot escape and by repelling the electrons on the inside foil, prevent any attempted concentration of electrons there.

Use a piece of heavy insulated wire to discharge the Leyden jar. Hold one end of the wire against the outer tinfoil. Bring the other end close to the knob. A spark leaps the gap. The greater the charge, the greater the spark. Of course, you can discharge the jar by holding the jar in one hand and touching the knob with a finger of the other hand. However, the effect on your nerves would be SHOCKING. Remember this any time you intend to work with a condenser.



CHAPTER 2

ELECTRICAL CURRENT

AMPERES

As you know from personal experience, apply enough pressure in the right place and something moves. Apply electrical pressure to a copper wire, and the free electrons of the atoms move forward to other atoms. The movement of these electrons is an electric current. In figure 4 you have cross-sections of copper wires. The artist has enormously magnified the copper atoms so as to picture for you their nuclei and electrons.

The strength, or INTENSITY, of the current depends upon the number of electrons moving or flowing along. The more the electrons moving along, the higher the intensity of the current.

The intensity of a current is expressed in AMPERES. One ampere is the movement of a certain number of electrons past a given point in

the conductor EACH SECOND. Double this number of electrons going by a given point every second, and you have two amperes. Triple the number

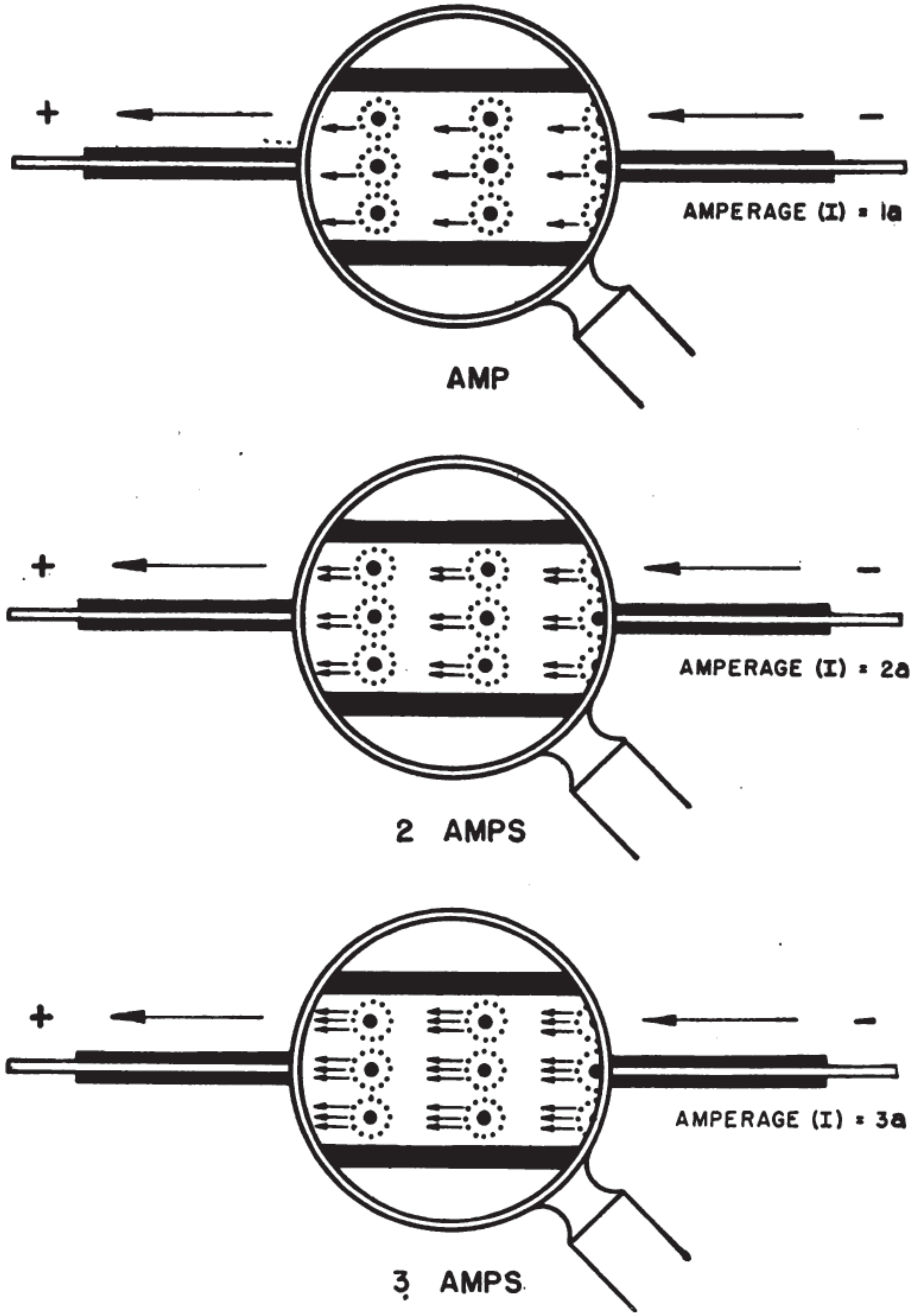


Figure 4.—Amperage.

going by every second, and you have three amperes.

The number of amperes is known as the AMPERAGE. You represent amperage by the capital letter I—an abbreviation of the word INTENSITY.

QUANTITY vs. QUANTITY PER SECOND

Amperage is NOT an expression of quantity. It IS an expression of quantity PER SECOND.

A gallon of water, for instance, is a certain quantity of water. But a gallon of water passing a given point in a pipe per second indicates a rate of flow. In electricity, the COULOMB corresponds to the gallon of water. It is a certain quantity of electrons. The quantity of electrons passing a given point in a conductor per second is measured in amperes.

DON'T FORGET—AMPERAGE IS RATE OF FLOW

TYPES OF CURRENT

When you have electrons flowing evenly along in one direction, you have a DIRECT CURRENT. If the strength of this direct current waxes and wanes rhythmically, or periodically, you have a PULSATING DIRECT CURRENT comparable to the pulsating flow of blood through an artery.

When you have a current that flows alternately in one direction and then in the opposite direction, you have an ALTERNATING CURRENT. Almost every alternating current reverses direction periodically, or rhythmically, a definite number of times per second. The number of complete reversals, or cycles, per second is known as the FREQUENCY. In most homes, the current is 60-cycle alternating current. In radio, you meet up with 300,000,000-cycle alternating currents.

VOLTS AND OHMS

To start electrons flowing and to keep them flowing, you must apply electromotive force

(emf). This force is also known as the VOLTAGE of a circuit. The symbol for voltage is E. Just as water pressure pushes water through a pipe, so voltage pushes electrons through a conductor.

A water pump builds up water pressure. A battery or an electric generator builds up electrical pressure. When free to flow, water flows downhill from a higher level to a lower level. In a pipe leading from a tank of water, the water pressure at any lower level depends upon the vertical distance from there to the surface of the water in the tank. It also depends upon the friction or resistance in the pipe through which the water flows.

If there is a difference in electrical level or pressure between two points on a conductor, the free electrons move and you have a current. This difference in voltage, or emf, is often termed DIFFERENCE IN POTENTIAL, or POTENTIAL DIFFERENCE. The word potential, as used in electricity, implies the capacity to move something along in spite of resistance.

The potential difference between two points on a conductor is measured in VOLTS. The resistance offered by the conductor is measured in OHMS. One volt is the emf needed to keep a current of one ampere flowing through resistance of one ohm.

The symbol of electrical resistance is R. Just as friction causes every pipe to offer resistance to the flow of water, so friction causes every conductor to offer resistance to the flow of electrons.

HOW VOLTAGE AND RESISTANCE AFFECT CURRENT

You can compare the flow of electrical current with the flow of water in the cooling system of an automobile engine.

As you see in figure 5, cooling water is pumped

to the top of a radiator by a water pump coupled to an engine. The amount of water delivered to the top of the radiator depends on the pressure that the water pump exerts. The strength of an electric current flowing through a LOAD CIRCUIT—that is, any electrical appliance—depends on the voltage of a battery.

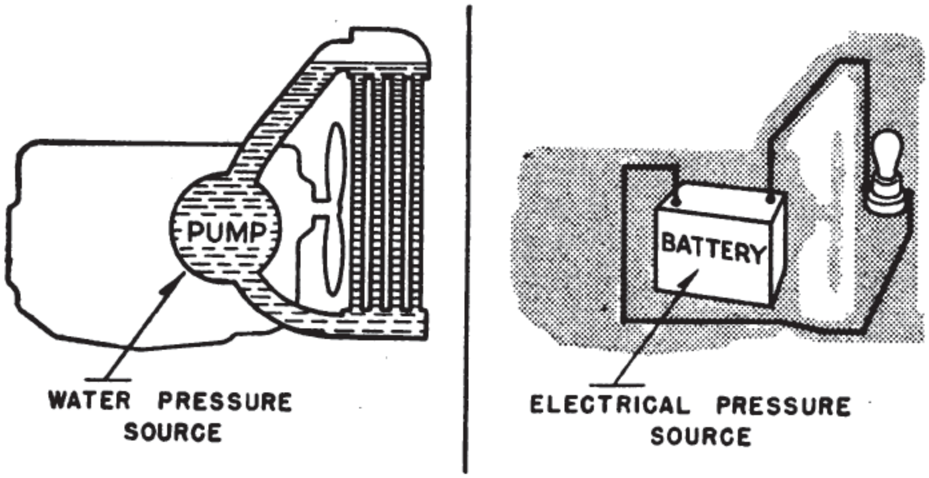


Figure 5.—Pump and battery compared.

An increase in electrical pressure, or voltage, forces more electrons through the load and connecting wires just as a higher pump pressure forces more water through the radiator of an automobile.

The flow of water in the radiator is retarded by the friction, or resistance, of the radiator. Because of deposits of rust, grease, or dirt on the walls of the tubes or hose connections, there may be an increase in the resistance. The effect of the resistance is to cut down the flow of water. Similarly, in the electrical circuits, an increase in the resistance of the load circuit causes a decrease in the strength of the electrical current. A decrease in resistance permits an increase in current strength.

For a play-by-play comparison, consult table I.

Table 1

AUTOMOBILE COOLING SYSTEM **Water Circuit**	SIMPLE ELECTRIC CIRCUIT **Electric Circuit**
Pump builds up water pressure to force a current of water through the radiator.	Battery builds up electrical pressure to force a stream of electrons—electrical current — through the lamp and connecting wires.
Higher pump pressure forces more water to flow through the radiator.	Higher voltage (more battary cells) forces a stronger electrical current through the lamp.
Lower pump pressure results in a smaller stream of water through the radiator tubes.	Lower voltage results in a weaker current through the lamp.
The radiator tubes have resistance (pipe friction) that opposes the flow of water.	The lamp and connecting wires have electrical resistance that opposes the flow of current.
Deposits of rust, dirt, or grease result in a smaller stream of water because of increased resistance.	An increase in the resistance of the lamp results in a weaker current through the lamp.
Removal of rust, grease, and dirt or substitution of larger tubes in the radiator results in a greater current of water.	Substituting a lamp with lower resistance results in a stronger current.

DIRECTION OF CURRENT FLOW

A voltage source, such as a battery, has two TERMINALS. One is the POSITIVE terminal, the other the NEGATIVE terminal.

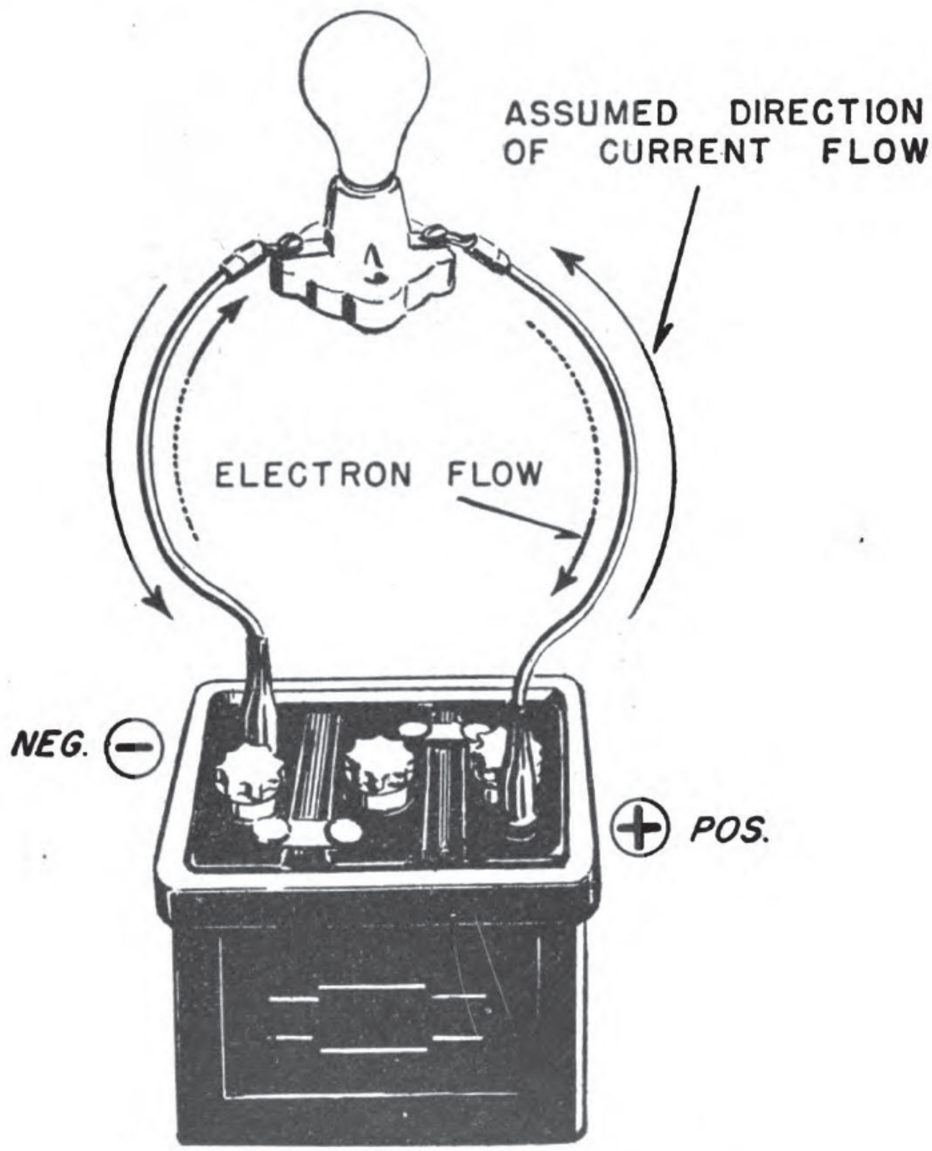


Figure 6.—Direction of current flow.

In figure 6, you see that the DIRECTION of the CURRENT FLOW is from the positive terminal to the negative terminal, while the DIRECTION of the ELECTRON FLOW is just the opposite.

This is a contradiction. After all, current flow and electron flow are the same thing. How CAN the current go ONE WAY and electrons go the OTHER? The answer is—they DON'T. Actually, current flow is in the same direction as electron flow. Electricians just ASSUME that current flow is from the positive terminal to the negative terminal.

WHY is a long story. Early experimenters had no way of KNOWING the direction of current flow. Ben Franklin guessed it was from positive to negative. He guessed wrong. And this wrong conception is still used today, even though electricians know it is wrong. You'd have to change millions of wiring diagrams and most of the books on electricity to get the record straight.

This book ASSUMES the "conventional" view that current flow is from POSITIVE to NEGATIVE. You shouldn't run into any difficulty with this contradiction until you get to vacuum tubes. Then you'll see how this wrong guess sort of complicated the advancement of the understanding of electricity.

CHAPTER 3

ELECTRIC CIRCUITS

DIAGRAMS

Men who know electricity best, "talk with diagrams." Ask them a question, and they whip out a pencil and make a quick sketch to show you what's what. In telling a technical story, a single diagram is often worth more than a thousand words in putting over the POINT of the story.

Generally, one of two types of diagrams is used to explain electrical installations. You MUST understand these types before you go any further with your study of electricity.

Certain structural parts of a circuit, as well as connection wires, are shown in a WIRING DIAGRAM. In a SCHEMATIC DIAGRAM, electrical parts are represented by symbols and only the scheme of the connection is indicated.

The two diagrams in figure 7 show exactly the same thing. Both illustrate the connection pattern of coils in an electric motor. Note that the schematic diagram uses a form of shorthand.

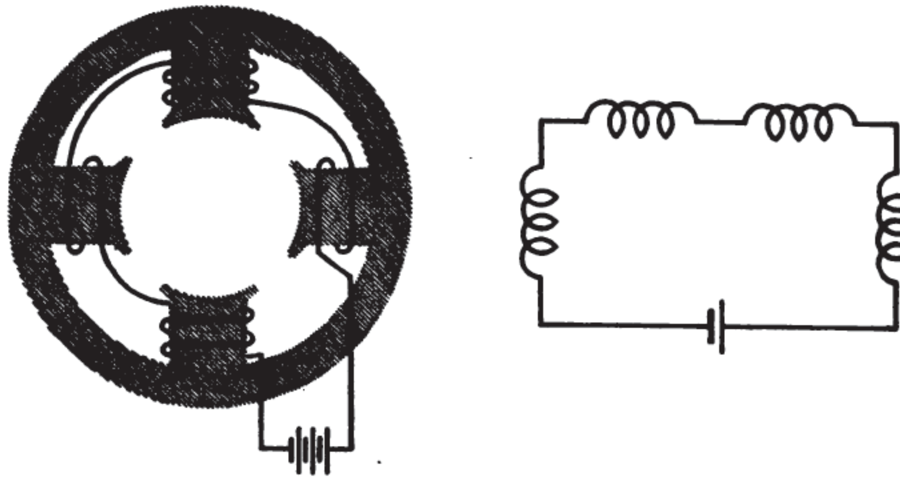


Figure 7.—Types of diagrams.

In figure 8, you have three lamps connected to a storage battery. Note the TWO common methods of representing wire connections in schematic diagrams.

By the method in A, you use a U, or loop, to show a crossing of two wires that are NOT con-

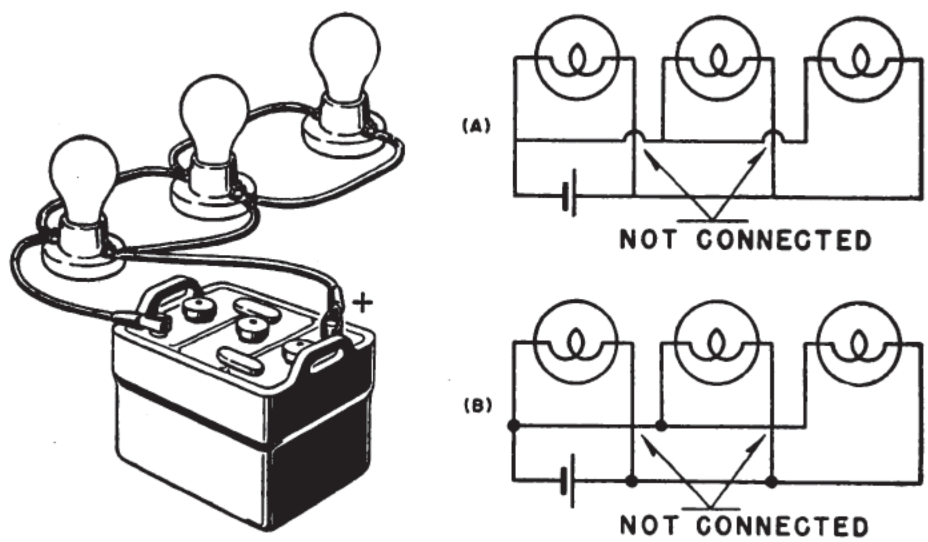


Figure 8.—Wire connections.

nected, and you show a connection by a crossing at right angles.

By the method in *B*, a crossing point of two

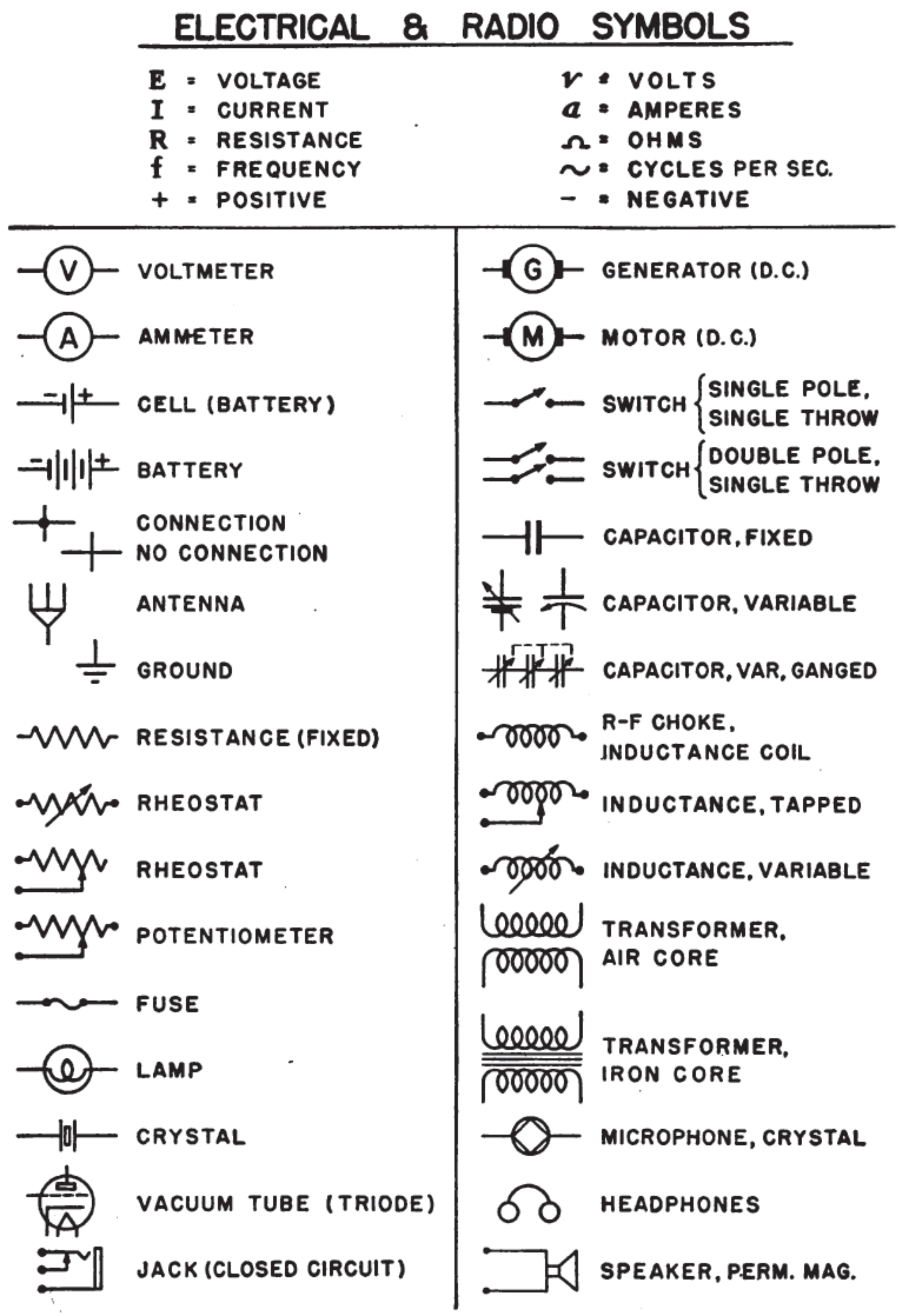


Figure 9.—Electrical symbols.

wires is a connection ONLY if you place a DOT there.

The TABLE OF ELECTRICAL SYMBOLS, figure 9, gives you a set of symbols widely used in electrical and radio work.

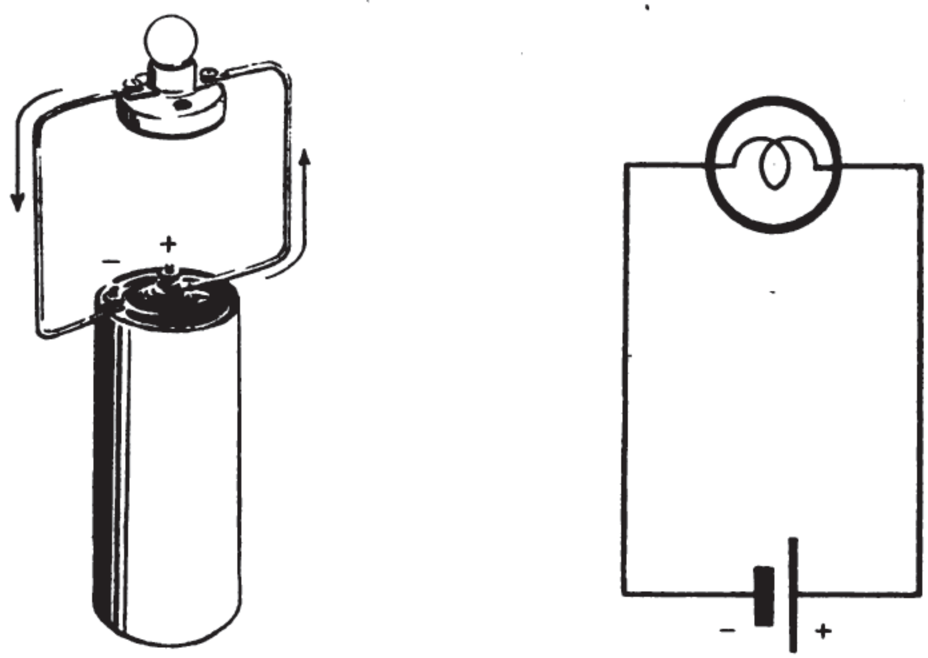


Figure 10.—A simple circuit.

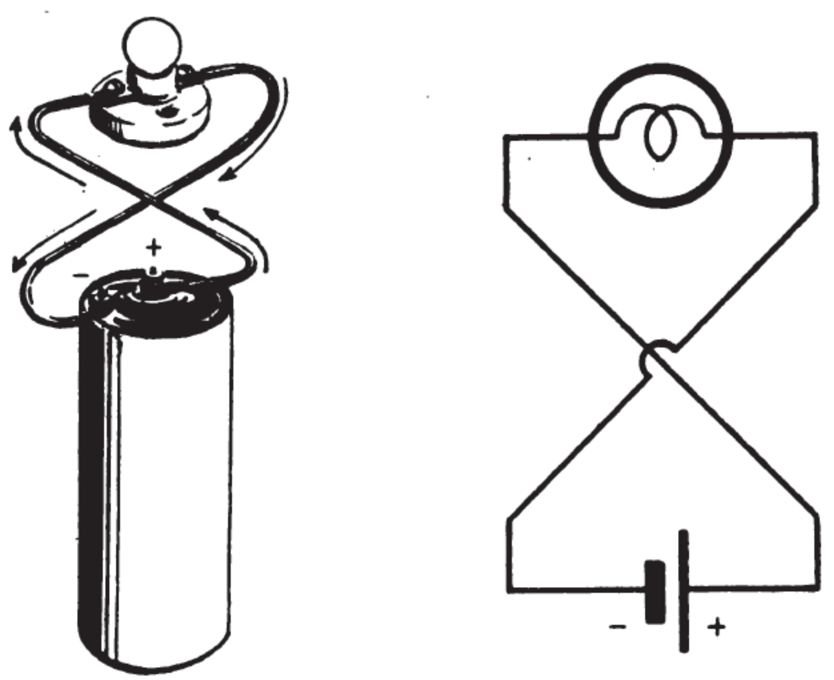


Figure 11.—Still a simple circuit.

SIMPLE CIRCUIT

When you have a circuit made up of ONE device or appliance, a voltage source, and connecting wires, you may call it a SIMPLE CIRCUIT. In figure 10, you have the schematic diagram for such a circuit.

With one device and a voltage source, you ALSO may connect the device as you see in figure 11. You merely reverse the direction of the current through the device. You STILL have what is essentially a simple circuit.

SERIES CIRCUIT AND PARALLEL CIRCUIT

With only ONE device, you must always use a simple circuit. But when TWO or more devices are connected to the SAME voltage source, you may connect them in either PARALLEL or SERIES circuits.

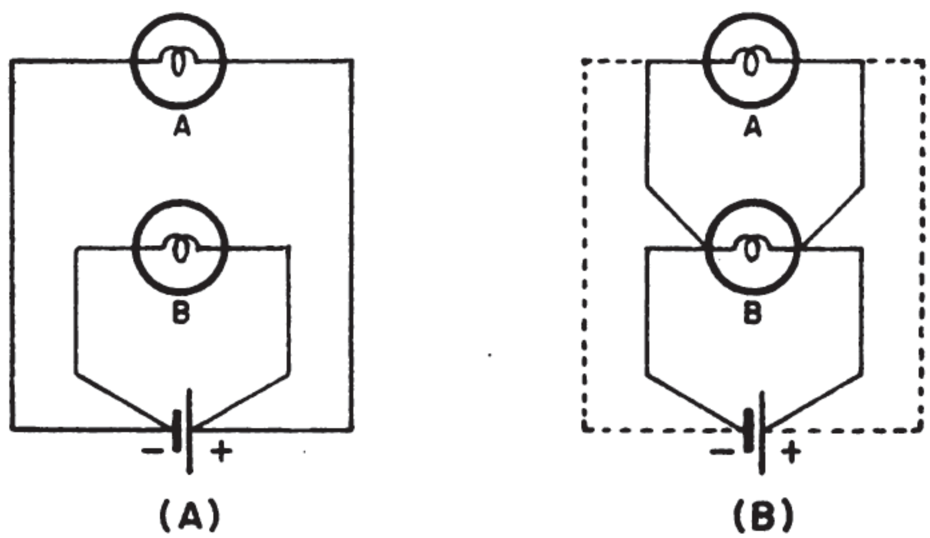
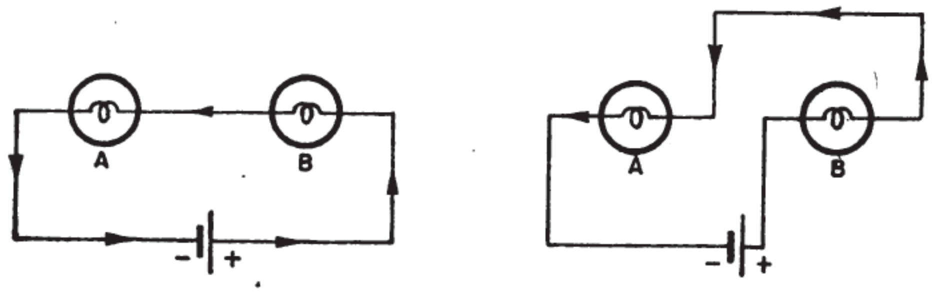


Figure 12.—Parallel circuit.

In (*A*) of figure 12, you have an illustration of two lamps connected in a PARALLEL CIRCUIT. In (*B*) of figure 12, you also have a parallel circuit. But the connections from device *A* are brought to device *B*. This results in a saving of wire.

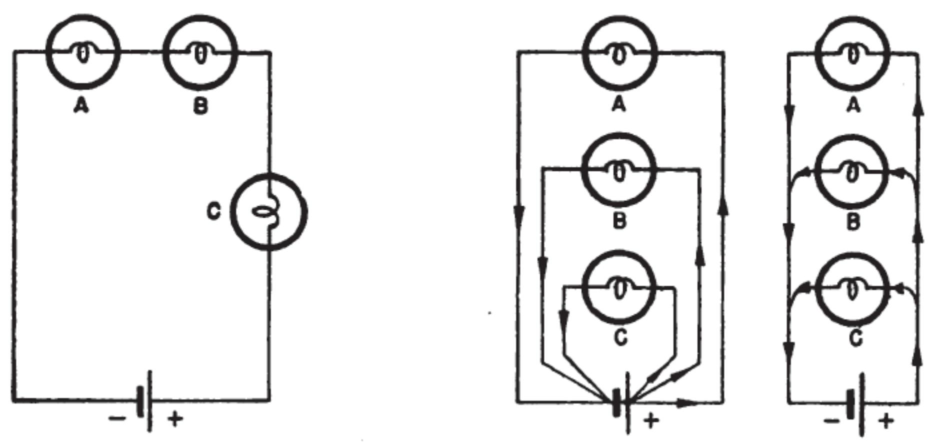
In (*A*) of figure 13 you have two devices connected in a SERIES CIRCUIT. In (*B*) of figure 13, the connections are changed so that they reverse



(A) (B)

Figure 13.—Series circuit.

the current through device *B*. But the lamps are still in series. Now look at the comparison of series and parallel circuits in figure 14.



(A) (B) (C)

Figure 14.—(*A*) Series circuits and (*B*), (*C*), parallel circuits.

The following rules should help you to tell at a glance whether you have a series circuit or a parallel circuit.

SERIES	PARALLEL
There is only one path for the current.	There are as many paths for the current as there are devices.
The devices depend on one another for operation. Failure or removal of one device breaks the circuit and halts all flow of current.	The devices are independent of one another. Failure or removal of one device does not halt the current through the others.
No terminal is connected to more than one other terminal.	All positive terminals are connected together, and all negative terminals are connected together.

SERIES-PARALLEL CIRCUIT

When you combine a series circuit and a parallel circuit into one circuit, you have what is known as the SERIES-PARALLEL CIRCUIT. Many combinations are possible.

(In (*A*) of figure 15, devices *C* and *B* are "in parallel" with each other. Devices *C* and *B* considered as a group (everything within the shaded area) are "in series" with *A*. In (*B*) of figure 15, devices *C* and *B* are "in series" with each

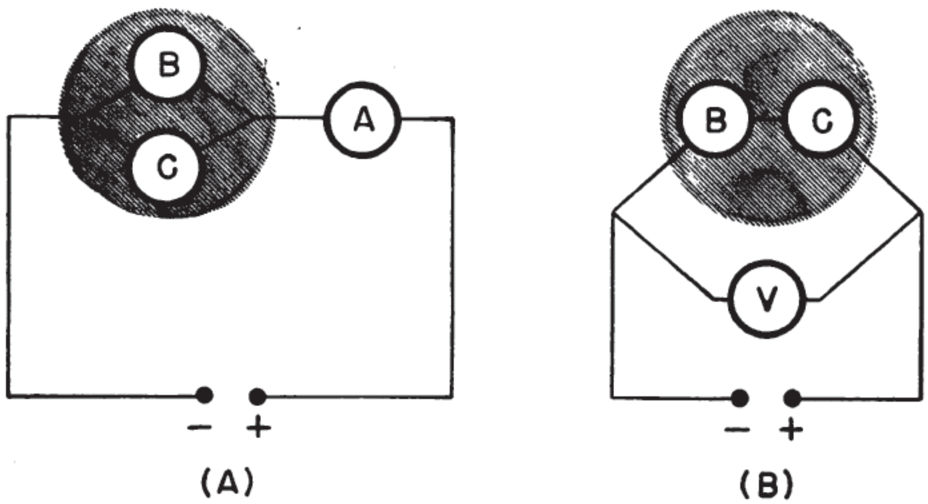


Figure 15.—Series-parallel circuits (3 devices).

other. Devices *C* and *B* as a group (everything within the shaded area) are "in parallel" with device *V*.

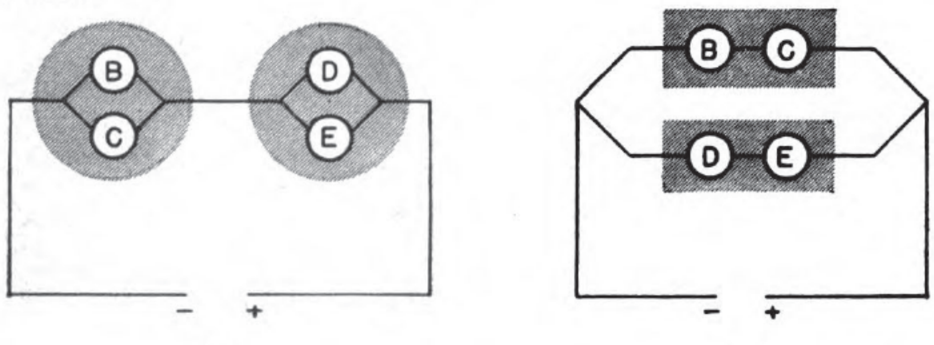


Figure 16.—Series-parallel circuits (4 devices).

In (*A*) of figure 16 the circuit parts within the shaded area are in parallel. The contents of one shaded area are in series with the contents of the other shaded area.

B is in parallel with *C*.

E is in parallel with *D*.

B and *C* are in series with *E* and *D*.

In (*B*) of figure 16, the circuit parts within the shaded areas are in series. The contents of one shaded area are in parallel with the contents of the other shaded area.

B is in series with *C*.

E is in series with *D*.

B and *C* are in parallel with *D* and *E*.

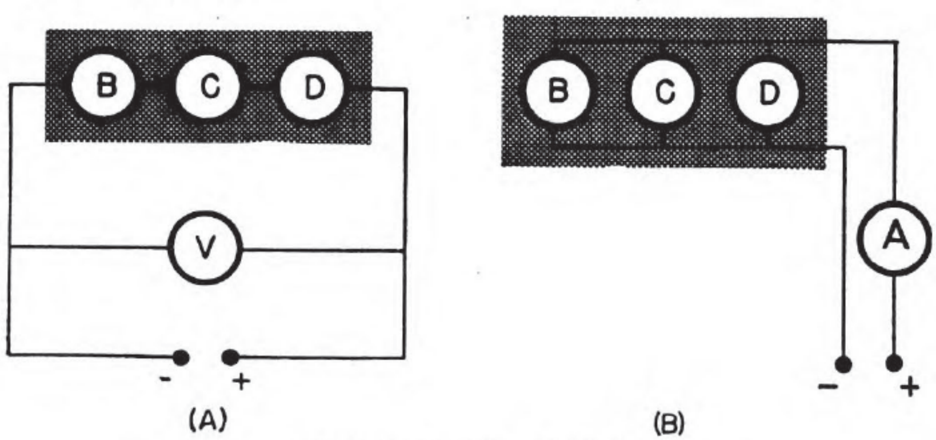


Figure 17.—More series-parallel circuits.

In (*A*) of figure 17, *B, C,* and *D* are in series with each other. *V* is in parallel with *B, C,* and *D* as a group.

In (*B*) of figure 17, *B, C,* and *D* are in parallel with each other.

A is in series with *B, C,* and *D* as a group.

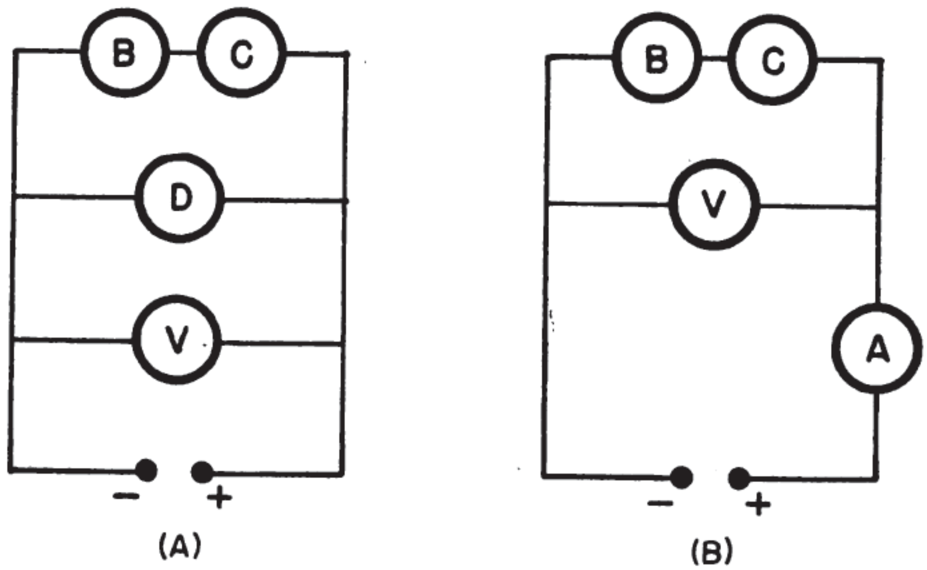


Figure 18.—Still more series-parallel circuits.

In (*A*) of figure 18, *B* and *C* are in series with each other. *D* and *V* are in parallel with each other and with *B* and *C* as a group.

In (*B*) of figure 18, *B* and *C* are in series with each other, and, as a group, are in parallel with *V*. *A* is in series with *B, C,* and *V* as a group.

GROUNDED CIRCUITS

To save wire and to make simpler connections, you can use the earth or other conducting materials as part of a circuit. This trick is known as GROUNDING. See figure 19, in which the earth is part of the lamp circuit. In automobiles and airplanes, where earth connections are impossible, the metallic portions of the chassis or fuselage may be used for grounding purposes. The con-

ducting material acts as a "return" wire or as a "feed" wire in grounded circuits.

In figure 19 you have the headlights of an automobile in a connection which makes use of the car chassis as the return wire. The lamp current

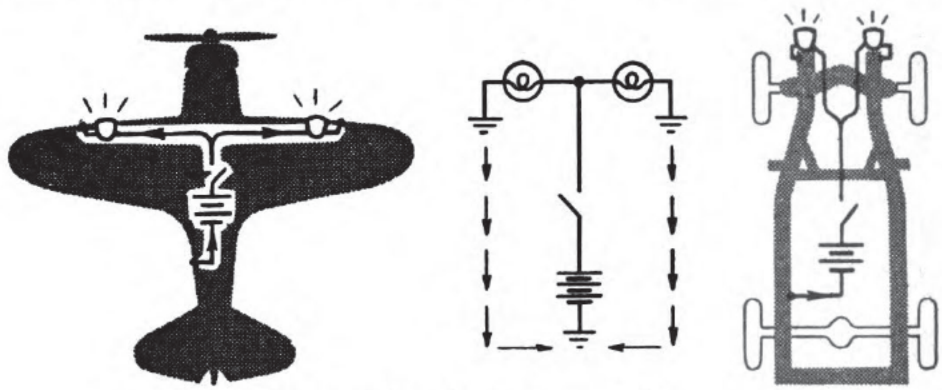


Figure 19.—Negative grounding.

passes through the chassis in returning to the battery. The same circuit may be used in an airplane (as illustrated) with the metallic fuselage acting as a conductor. This is known as NEGATIVE GROUNDING because the negative terminal of the battery is attached to the grounding material.

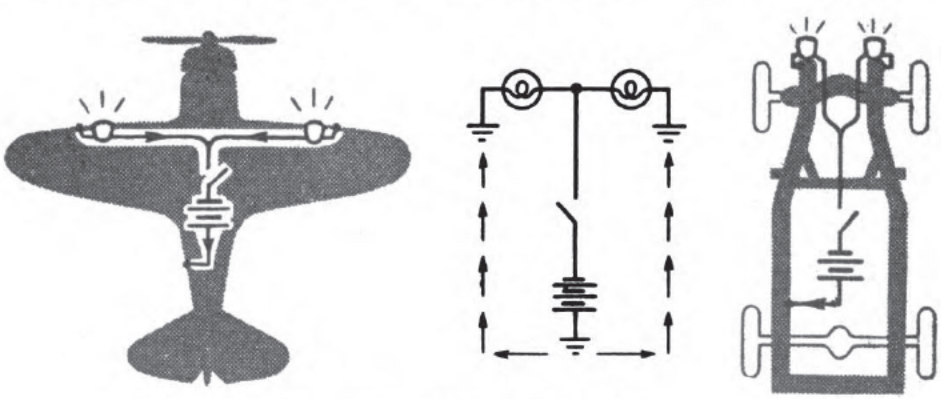
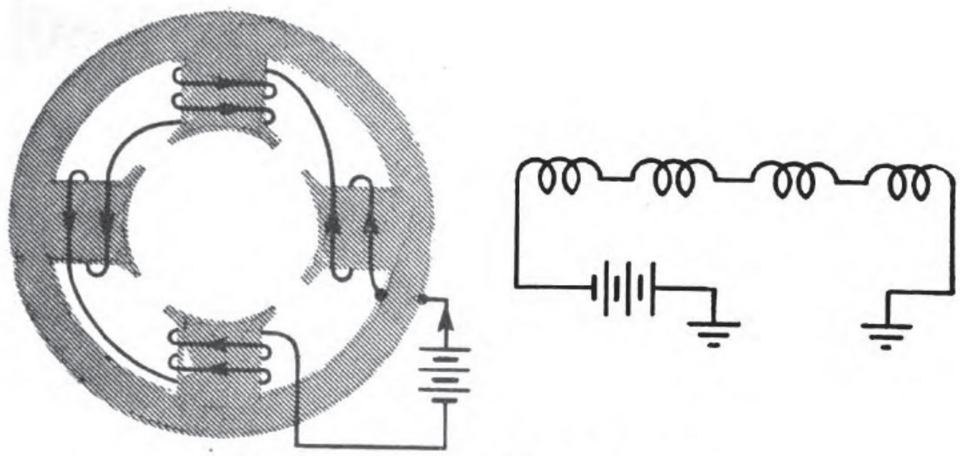
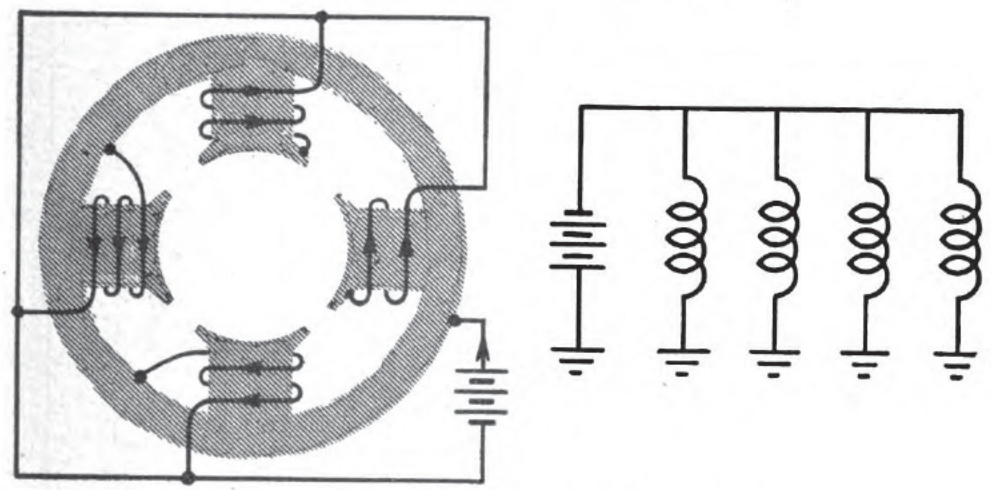


Figure 20.—Positive grounding.

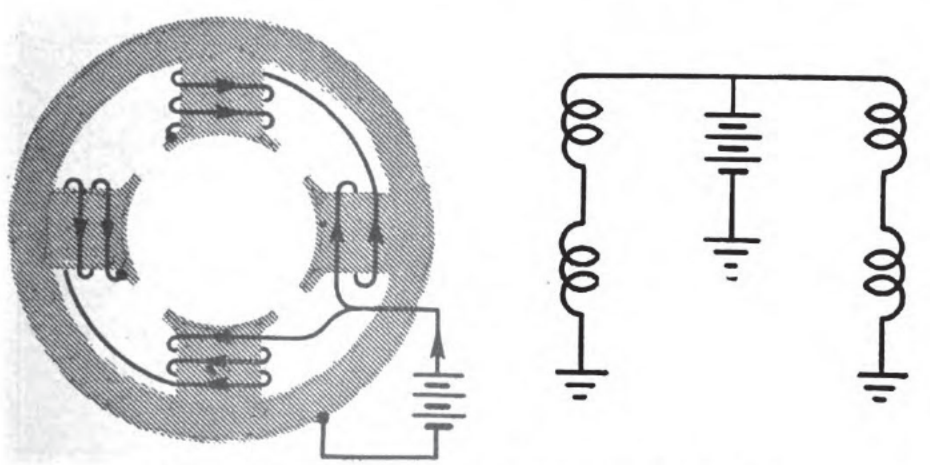
When you attach the positive terminal of the battery to the grounding material, so that it acts as a feed wire, you have what is known as POSITIVE GROUNDING. You have an example of positive grounding in figure 20.



SERIES-POSITIVE GROUND



PARALLEL-POSITIVE GROUND



SERIES-PARALLEL-POSITIVE GROUND

Figure 21.—Grounding in a circuit of a motor.

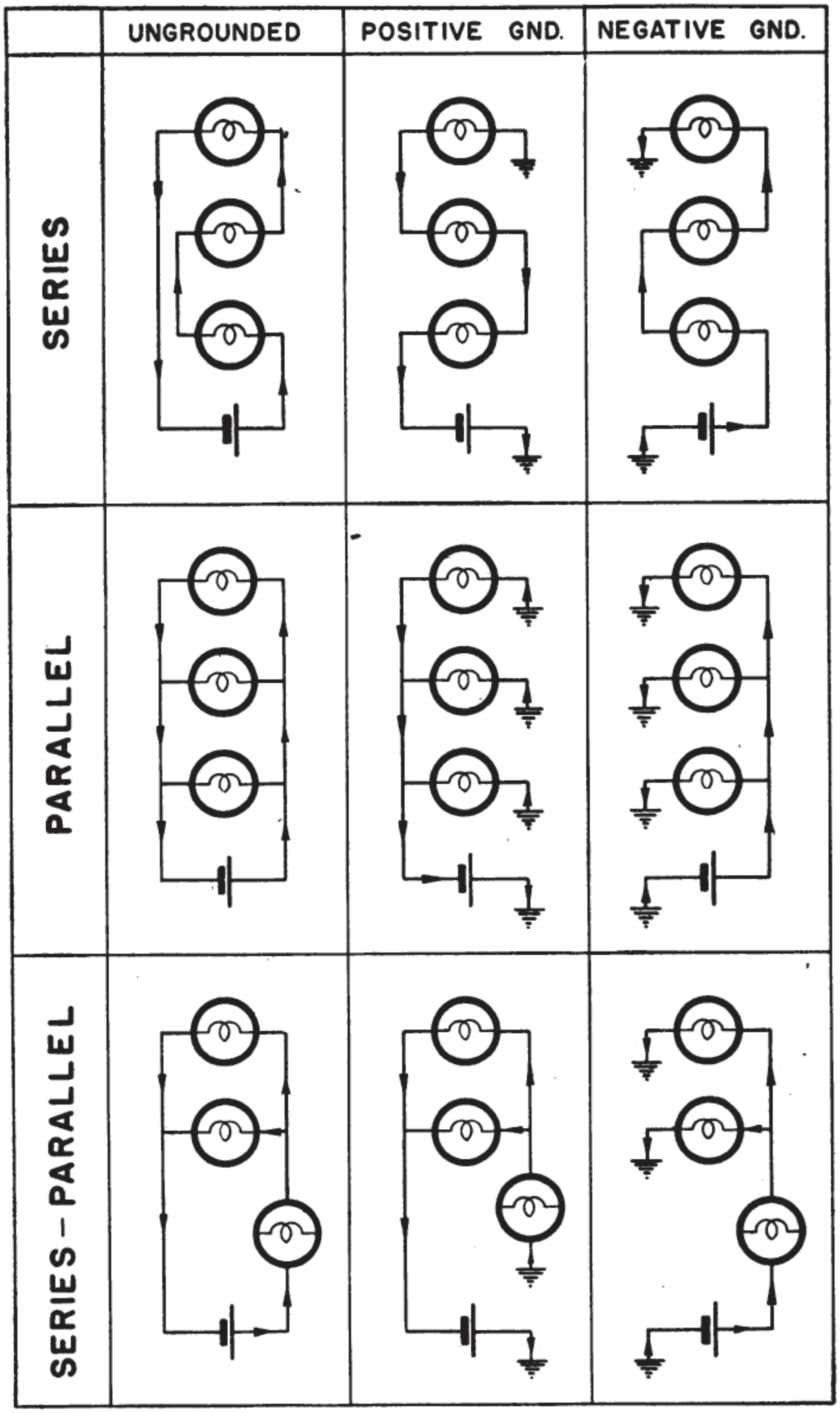
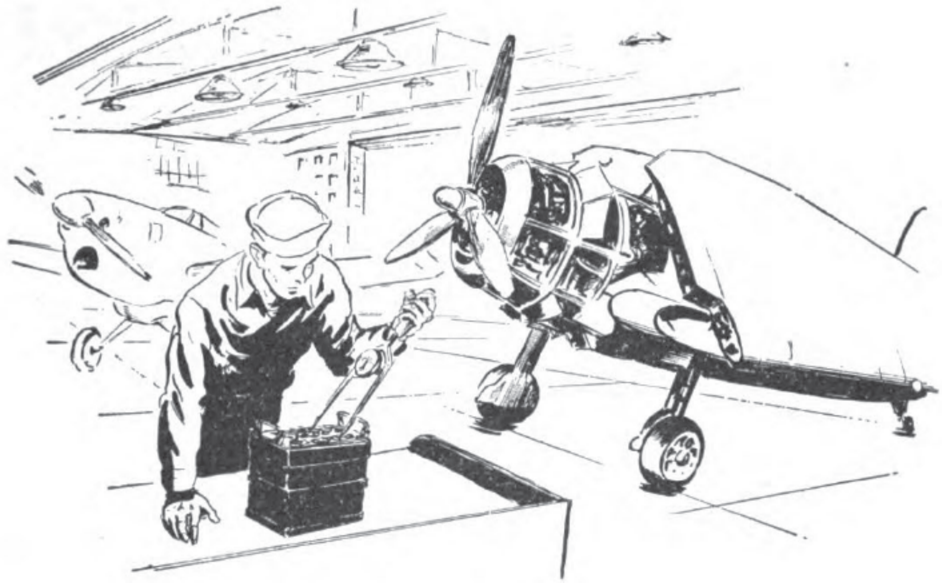


Figure 22.—General circuits.

Grounding principles are also applied to the wiring connections within an electrical device. In figure 21, you can follow the internal wiring connections of one circuit of a four-pole starter motor employing positive grounding.

In figure 22, you have diagrams for connecting three devices in series, parallel, and series-parallel by the use of negative and positive grounding. Be sure you understand why each is different from the others.



CHAPTER 4

OHM'S LAW

WHAT IS IT?

You already know that the strength of an electrical current depends on the electrical pressure and the resistance. Ohm's Law states the relationship of these three factors in mathematical terms. It says—

$$I=\frac{E}{R}$$

That is, an electrical current I (in amperes) in a circuit equals the electrical pressure E (in volts) divided by the resistance R (in ohms).

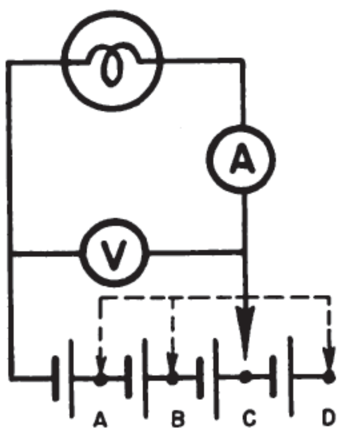
CHANGE E, AND YOU CHANGE I, IF,— the resistance in a circuit remains constant.

Take a look at figure 23. You have in this diagram a basic electrical circuit with a load, a voltage source, and connecting wires. The load may be any electrical appliance. The voltage

source may be either a battery or a generator. In this case, it is a series of battery cells.

The current I is measured by an AMMETER IN SERIES with the load. The electrical pressure E is measured by a VOLTMETER IN PARALLEL with the voltage source. The positive wire from the load may be connected at points A, B, C, or D to give, respectively, a pressure of 2, 4, 6, or 8 volts.

If you keep the resistance R at 2 ohms and step up the pressure E by connecting the positive lead successively to A, to B, to C, to D, you will get the ammeter and voltmeter readings listed in the table at the right of the diagram. Note that when you increase E, I increases in proportion. When you decrease E, I decreases in proportion.



POSITION	E	I	R
A	2	1	2
B	4	2	2
C	6	3	2
D	8	4	2

Figure 23.—Effect on voltage on current (*R* constant).

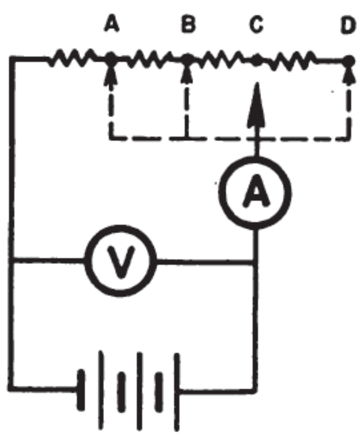
CONCLUSION—

In any electrical circuit, IF YOU HOLD THE RESISTANCE CONSTANT AND INCREASE THE VOLTAGE, YOU INCREASE THE CURRENT IN PROPORTION TO THE INCREASE IN VOLTAGE. IF YOU HOLD THE RESISTANCE CONSTANT AND DECREASE THE VOLTAGE, YOU DECREASE THE CURRENT IN PROPORTION TO THE DECREASE IN VOLTAGE.

CHANGE R, AND YOU CHANGE I, IF—
the voltage in a circuit remains constant.

Take a look at figure 24. You have in this diagram a circuit whose resistance can be changed while you keep the emf unchanged. The voltmeter reading is maintained at 6 volts. The lead from the ammeter may be connected at points *A*, *B*, *C*, and *D* to give, respectively, a load resistance of 2, 4, 6, or 8 ohms. Again you use the ammeter to measure the current flowing through the load.

If you keep the pressure *E* at 6 volts and step up the current *I* by connecting the lead successively to *A*, to *B*, to *C*, to *D*, you will get the ammeter reading listed in the table at the right of the diagram. Note that when you increase *R*, *I* decreases in proportion. When you decrease *R*, *I* increases in proportion.



POSITION	E	I	R
A	6	3	2
B	6	1.5	4
C	6	1	6
D	6	.75	8

Figure 24.—Effect on resistance on current (*E* constant).

Conclusion—

In any electrical circuit, IF YOU HOLD THE VOLTAGE CONSTANT AND INCREASE THE RESISTANCE, YOU DECREASE THE CURRENT IN PROPORTION TO THE INCREASE IN RESISTANCE. IF YOU HOLD THE VOLTAGE CONSTANT AND DECREASE THE RESISTANCE, YOU INCREASE THE CURRENT IN PROPORTION TO THE DECREASE IN RESISTANCE.

And

inspection of the tables contained in figures 23 and 24 will show you that any number in the cur-

rent column I can be obtained by dividing the number on the same line in the voltage column E by the number in the resistance column R. Remember, $I=\frac{E}{R}$.

Any number in the resistance column R can be obtained by dividing the number on the same line in the voltage column E by the number in the current column E, or $R=\frac{E}{I}$.

Furthermore, any number in the voltage column E can be obtained by multiplying the number on the same line in the current column I by the number in the resistance column R, or $E=I\times R$.

From your knowledge of mathematics, you can recognize that these three equations are variations of one formula.

$$I=\frac{E}{R},\ R=\frac{E}{I},\ \text{and}\ E=IR$$

If you know any two quantities, you can find the other by applying the proper equation.

FOR INSTANCE—

A vacuum tube filament has a resistance of 12 ohms when connected to a 6-volt storage battery. What current flows through the filament?

$$I=\frac{E}{R}=\frac{6}{12}=\frac{1}{2}\ \text{ampere}$$

An ignition coil draws 8 amperes at 6 volts. What is the resistance of the coil?

$$R=\frac{E}{I}=\frac{6}{8}=\frac{3}{4}\ \text{ohm}$$

A starter motor has a resistance of 0.04 ohm and draws 150 amperes at starting. Apply what voltage?

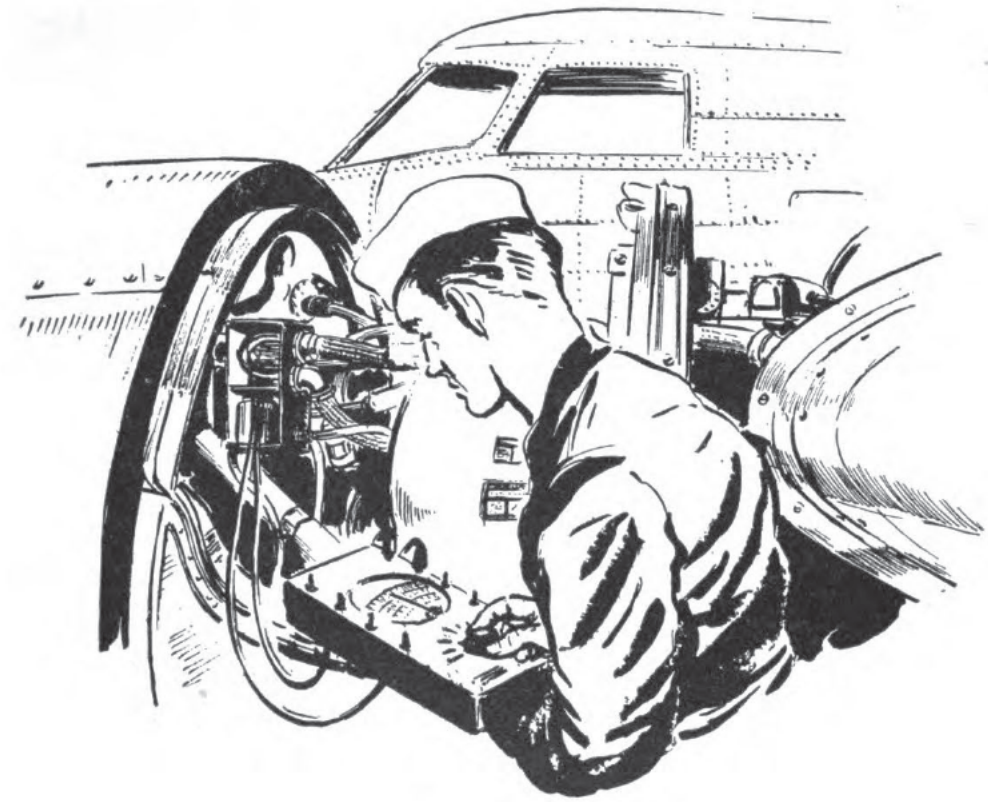
$$E=IR=0.04\times 150=6\ \text{volts}$$

REMEMBER THIS—

The strength of an electrical current, or amperage, depends on the RESISTANCE of the circuit AND the VOLTAGE applied to the circuit.

The resistance does NOT depend upon EITHER the voltage or the current. The resistance depends upon the character of the conducting path through the load—that is, upon the type and number of appliances. You DON'T change the resistance by changing voltage or current.

The voltage does NOT depend upon EITHER current or resistance. The voltage depends on the emf built up by battery or generator. Ohm's Law will help you to calculate the voltage required to send a given current through a given resistance.



CHAPTER 5

ELECTRICAL MEASUREMENTS

d-c CIRCUITS

You need different types of instruments for measuring different types of circuits. You can use d-c voltmeters and ammeters for measurement in d-c circuits ONLY. You must have a-c meters for low frequency a-c circuits, although some types of a-c meters can be used in d-c circuits. For high frequency current, you must have special types of meters. In this chapter, you meet up with instruments only for d-c circuits.

AMMETERS

In *A* of figure 25, you have a circuit with lamp, battery, and connecting wires. You measure the strength of the current through the lamp

by placing the ammeter IN SERIES with the lamp. All current flowing through the lamp must also flow through the ammeter. You can place the ammeter on EITHER side of the lamp, as in *B* and *C*, and the readings are the same.

When you connect the ammeter into the circuit, you naturally add some resistance. But the resistance of the ammeter is practically negligible. YOU MUST BE CAREFUL to connect the ammeter IN SERIES. Because the ammeter has very low resistance, the current through the instru-

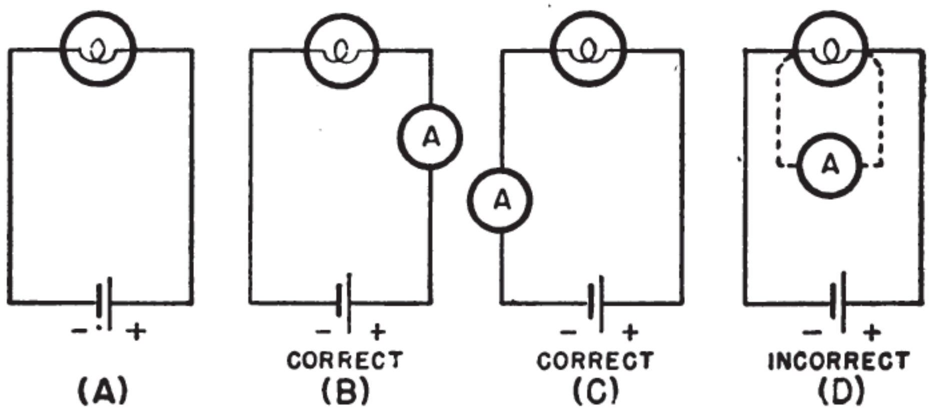


Figure 25.—Ammeter connections.

ment would then be excessively high. A sure way to WRECK the instrument is to connect it in parallel as you see in *D* of figure 25.

You can use an ammeter to measure the TOTAL CURRENT through a circuit or to measure the current through only a PART of the circuit. In *A* of figure 26, you see the ammeter connections for measuring the TOTAL current in a circuit. The ammeter is in series with ALL the devices as a group. In *B* of figure 26, you see the connection for measuring the current through one PART of the circuit. The ammeter is in series with ONLY THIS PART of the circuit.

In figure 27, note that the terminals of a d-c ammeter are marked with a plus (+) and a

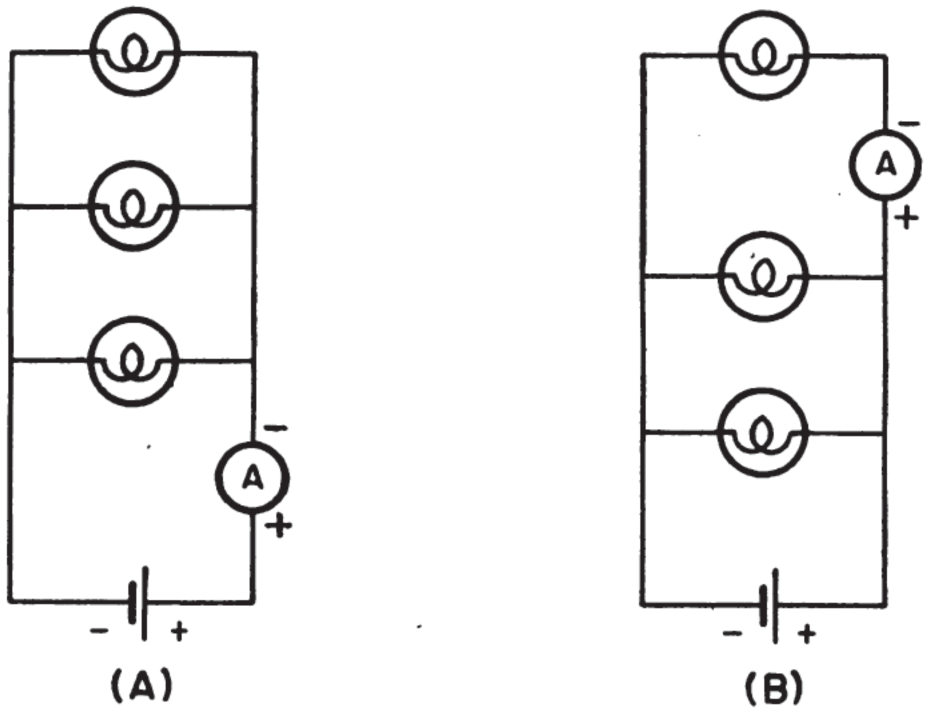


Figure 26.—*A*, measuring total current through a circuit, and *B*, measuring current through one device.

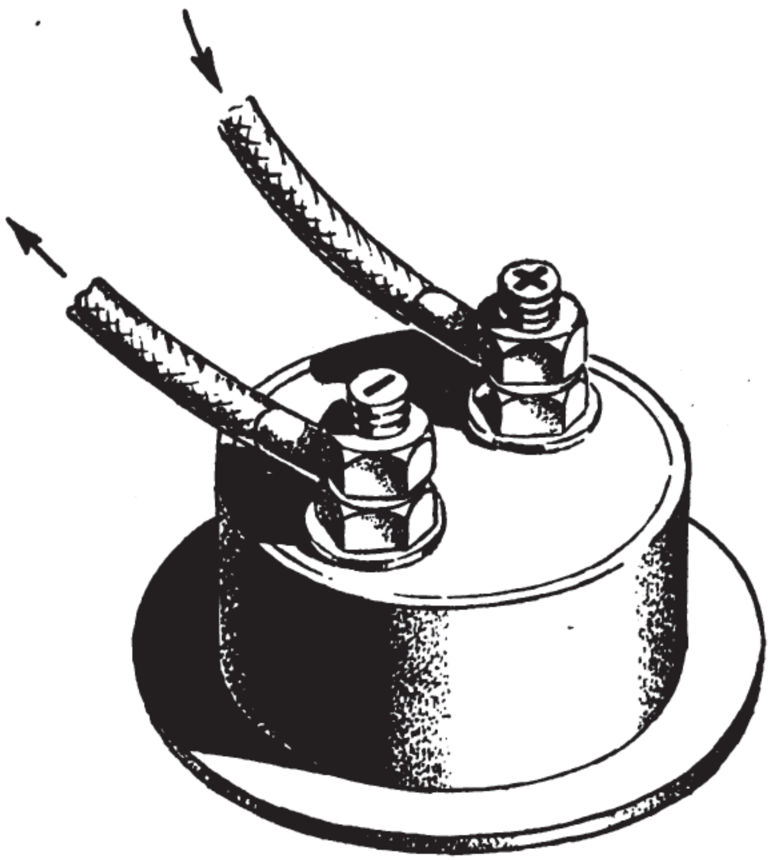


Figure 27.—d-c ammeter—marked terminals.

minus (−) sign. WHY? Because current must be sent through in the right direction to make the pointer swing correctly. THE CURRENT MUST BE MADE TO FLOW INTO THE POSITIVE TERMINAL OF THE AMMETER. Otherwise, the pointer moves in the wrong direction, against the stop. A ZERO CENTER AMMETER, such as you have in figure 28, can measure current flowing in either direction. The zero center ammeter is used in all generator-battery circuits, such as in automobiles and airplanes.

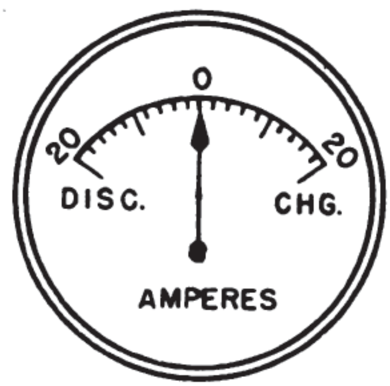


Figure 28.—Zero center ammeter.

Before you place an ammeter in a circuit, you should know approximately the current strength in the circuit. Each ammeter is made to measure current only within the limits marked on the scale of the instrument. A current that is in excess of the meter limits causes the pointer to strike the stop on the end of the scale—perhaps so violently that the pointer is damaged. Too high a current burns out the moving coil inside.

AMMETER SHUNT

A SHUNT is a conductor linking two points in a circuit so as to form a parallel or divided circuit through which a portion of the current may pass. Its purpose is to regulate the amount of current passing in the main circuit.

A shunt connected to the terminals of an ammeter will "rob" the instrument of a certain definite part of the total current that would otherwise flow through the ammeter. See figure 29. By use of a shunt, you can measure a current higher than that indicated by the highest reading on the scale of the ammeter. Shunts vary, each shunt being specially made so as to have a specific resistance.

Suppose you use a "50-ampere" shunt with an ammeter having a 5-ampere maximum reading on the scale.

> THEN, the number of amperes flowing through the circuit is $50 \div 5 = 10$ times the reading on the ammeter. Thus, a maximum reading of 5 amperes on the ammeter scale indicates a current equal $10 \times 5 = 50$ amperes,

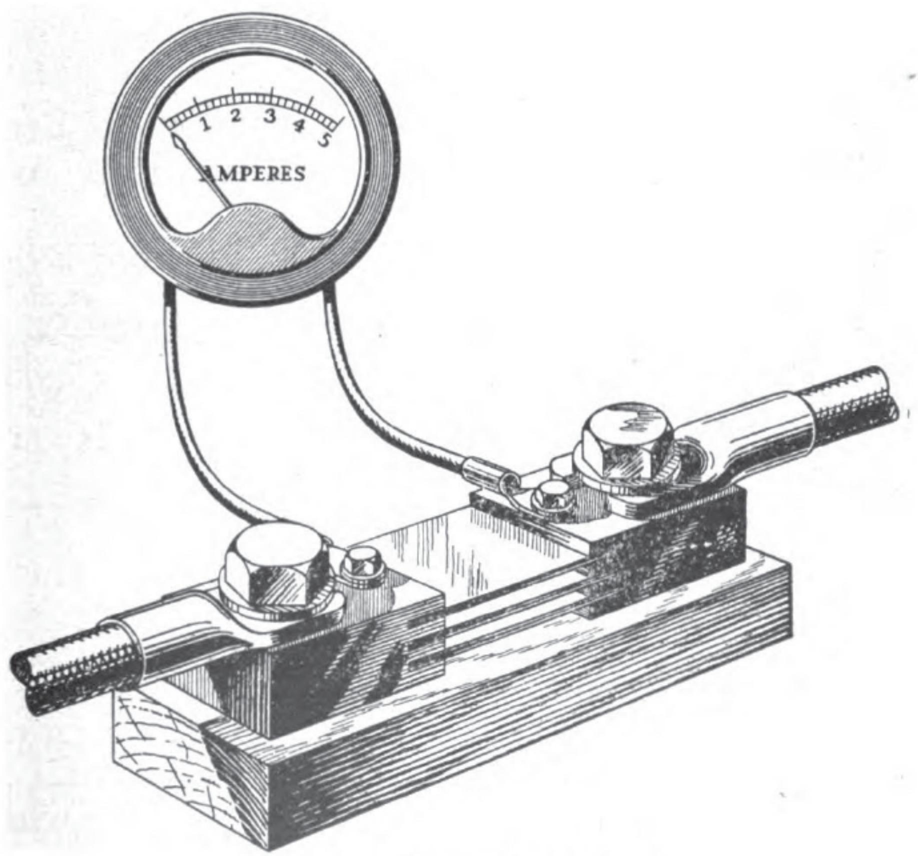


Figure 29.—Ammeter and shunt.

the rating on the shunt. Actually this means that 5 amperes pass through the ammeter and 45 amperes pass through the shunt. What about a reading of less than the highest possible reading, say 2.5 amperes? The current indicated is $10 \times 2.5 = 25$ amperes.

And so it goes. Find how many times greater your shunt rating is than the maximum possible reading of your ammeter. Then multiply that value by your actual reading on the ammeter.

Try another example. Suppose you have a 5-ampere ammeter, a 500-ampere shunt, and a reading of 1.25 amperes. The shunt rating, in this case is $500 \div 5 = 100$ times greater than the maximum possible ammeter reading, and the current indicated is $100 \times 1.25 = 125$ amperes.

VOLTMETERS

You'll recall that there must be electrical pressure between two points on a conductor or in a

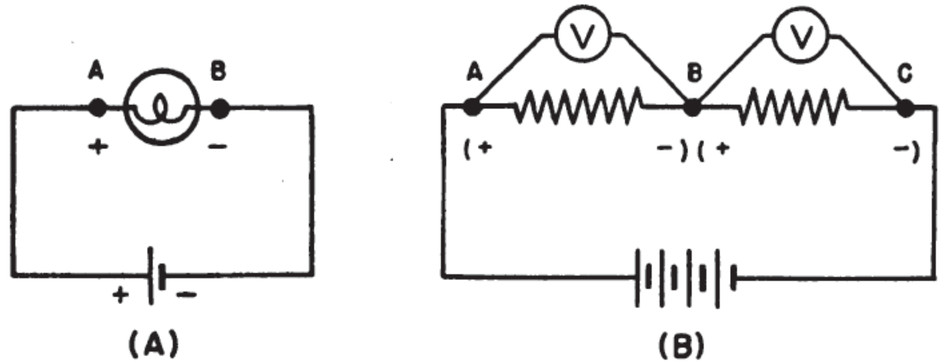


Figure 30.—Electrical polarity.

circuit to force along a current between these points. Thus, in (*A*) of figure 30, point *A* must be positive with respect to point *B* for current to be forced from *A* to *B*. In (*B*) of figure 30, when current flows from point *A* to point *B*, it only

does so because part of the voltage supplied by the battery acts between these points.

AND, because current does pass from A to B, point B must be negative with respect to point A.

Now, in this selfsame circuit, current goes from B to C. WHY? Same reason. Because B is positive with respect to C. Is it confusing that point B seems to be BOTH positive and negative? Of course not. Notice the words WITH RESPECT TO. You can see that B is negative WITH RESPECT to A, and positive WITH RESPECT to C. No point in a circuit can BY ITSELF be positive OR negative. A

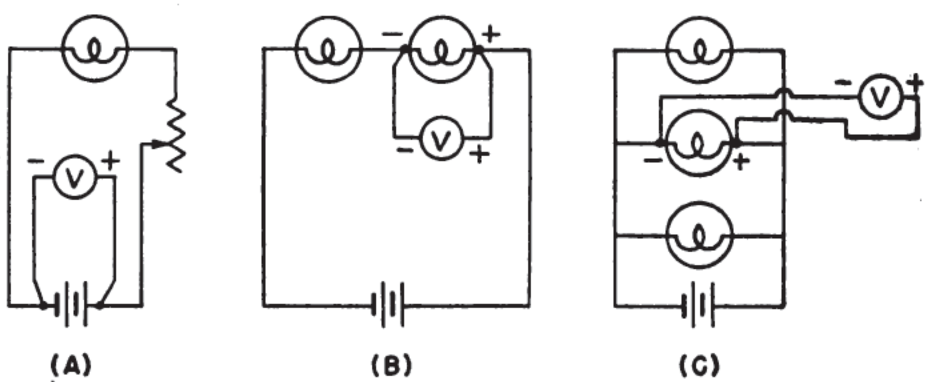


Figure 31.—Measuring voltage.

point has ELECTRICAL POLARITY only with respect to some other point in the circuit. Take a dry cell, for instance. One terminal is positive with respect to the other terminal of the selfsame cell. That's why current passes from the positive to the negative terminal when you connect the two.

To measure the voltage that exists between two points in a circuit, you must connect the voltmeter DIRECTLY to those points—that is, IN PARALLEL with that part of the circuit between the two points. In this way, you get the voltage across the two points. Or in other electrical words, you get the DIFFERENCE OF POTENTIAL between the two points. To measure the voltage of a battery, you connect the voltmeter leads to the positive and negative

terminals of the battery as in (A) of figure 31. To measure the voltage applied to a single path of the circuit, you connect the voltmeter directly ACROSS the terminals of that part, and thus get the potential difference, or voltage, between two points as in (B) and (C) of figure 31.

The terminals of a voltmeter are marked positive (+) and negative (—). You MUST connect the positive terminal of the voltmeter to the point from which the current is flowing (positive point), the negative terminal to the point to which the current is flowing (negative point).

A voltmeter is made to measure values of electrical pressure within limits marked on the scale. So, before you connect the instrument, you should know the approximate voltage value to be measured—else you MAY DAMAGE the pointer or moving coil.

RESISTANCE BY OHM'S LAW

You can measure resistance INDIRECTLY if you have a voltmeter and an ammeter and IF you can dash off the Ohm's Law formula. You get the voltage with the voltmeter, and the amperage with the ammeter—then you have values for E and I. So you write $R=\frac{E}{I}$, substitute the numerical values for E and I and SOLVE for R. In figure 32, you see how the ammeter-voltmeter method is used to find R in a simple circuit.

When you are measuring the R of any PART of a series or parallel circuit, you MUST remember that the current I, in the equation $R=\frac{E}{I}$, has to be the current THROUGH THAT PART ONLY. In figure 33, you have the ammeter and voltmeter connections for measuring the resistance of A PART of a series or parallel circuit.

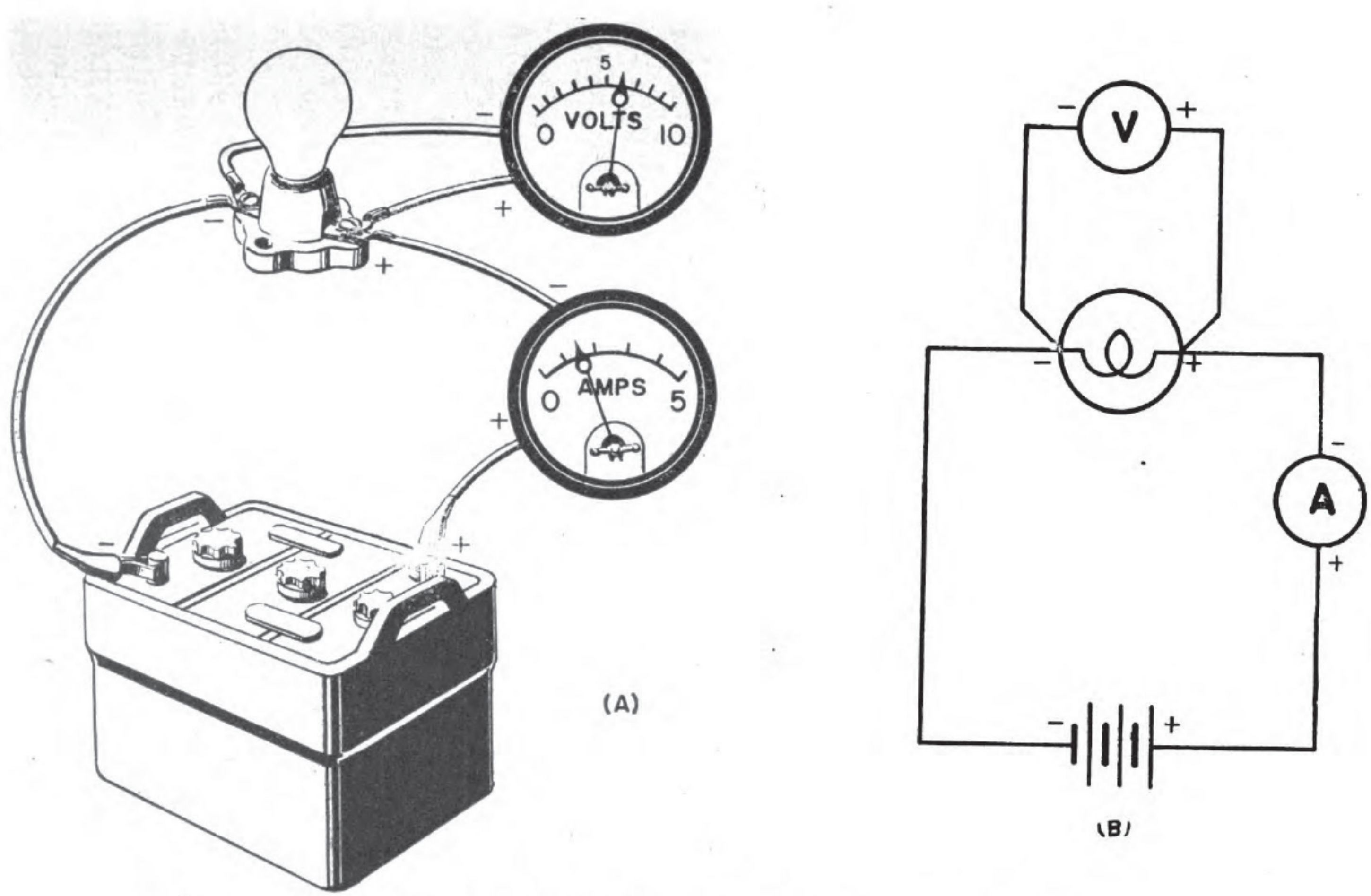


Figure 32.—Ammeter-voltmeter method of measuring resistance.

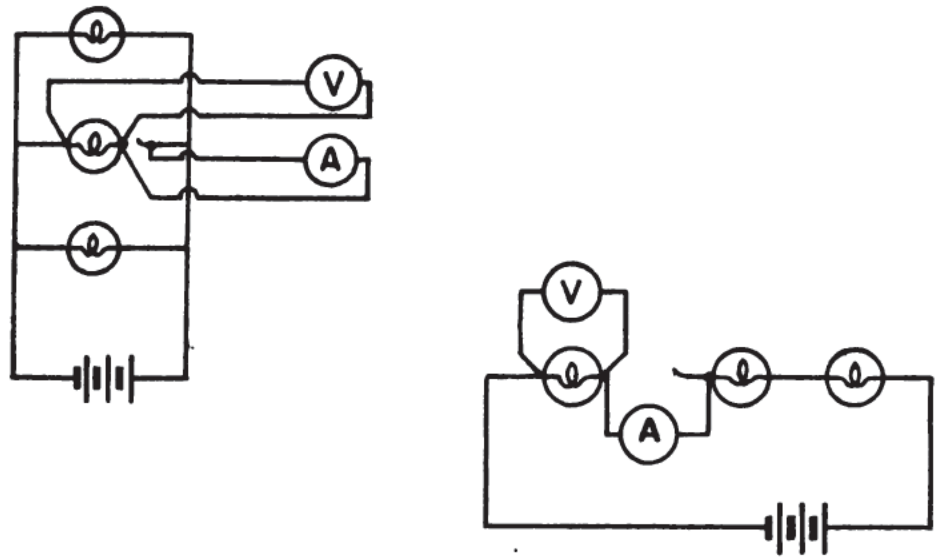


Figure 33.—Measuring resistance of part of a circuit—ammeter-voltmeter method.

RESISTANCE BY OHMMETERS

By use of an ohmmeter, you can measure resistance directly. You will find this a convenient method of locating trouble in a circuit, because damage to electrical equipment alters the resistance of the equipment and that of the associated circuit.

The simplest form of ohmmeter contains a voltage source WITHIN THE INSTRUMENT. Connect the instrument into part of the circuit and a small amount of current flows. This current MUST be the only current in the circuit when you have the ohmmeter connected. Other sources of voltage may damage the instrument.

In *A* of figure 34, there is diagrammed the connection of an ohmmeter for resistance measurement of ONE PART of a series circuit. Because no circuit current can be permitted to flow, the switch is open. You do not have to bother about electrical polarity in the case of the ohmmeter. The voltage source is within the ohmmeter, so the leads can be interchanged.

In *B* of figure 34, the ohmmeter has been placed ACROSS THE COIL. Now the ohmmeter measures the TOTAL RESISTANCE of the lamp and resistor as well as that of the coil. If you want to measure the

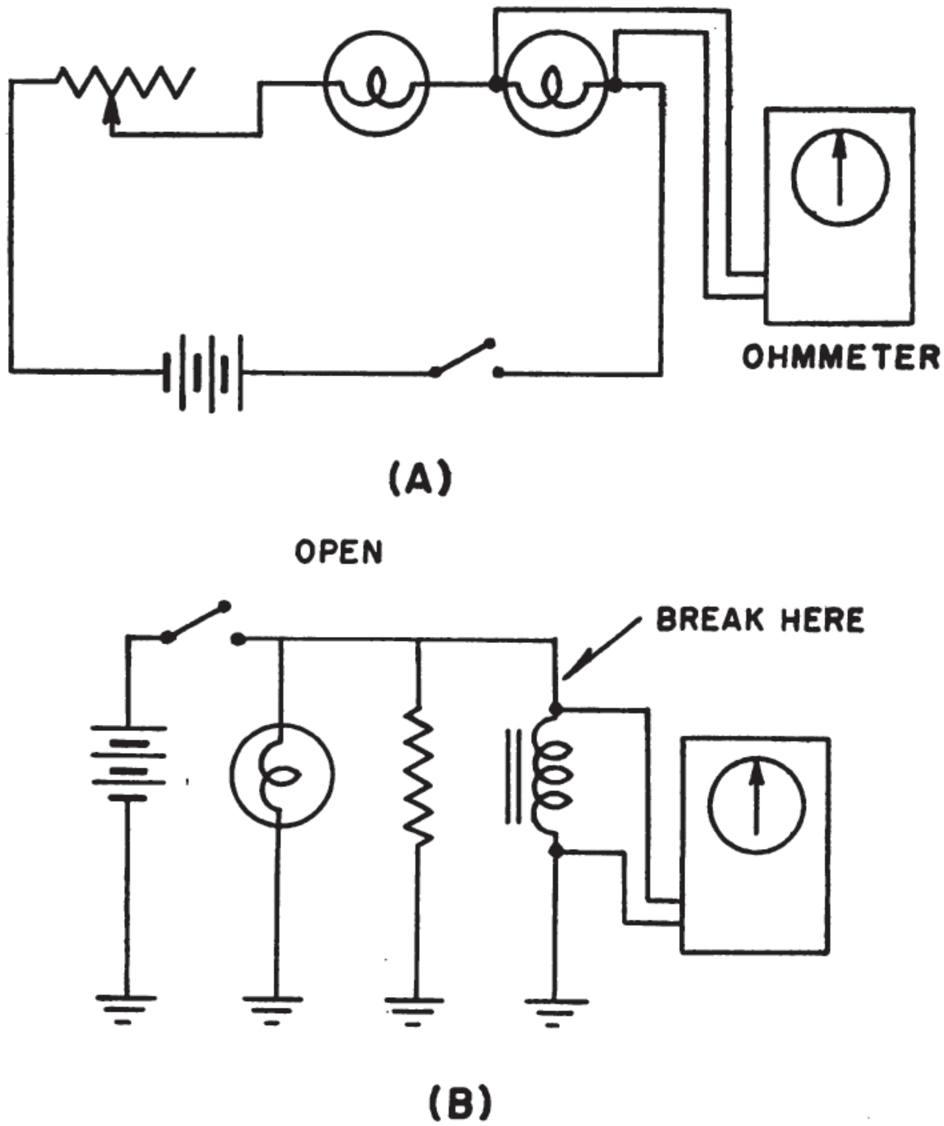


Figure 34.—Measuring resistance with an ohmmeter.

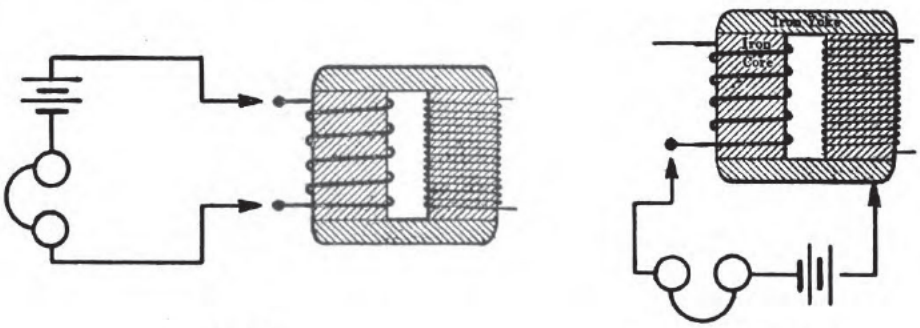
resistance of the coil alone, you must remove one of the connections to the coil.

Before you measure the resistance of ONE PART OF A PARALLEL circuit, you must disconnect that part. WHY? Because you do not want to include other circuit parts of the parallel combination.

Unless you observe this precaution, there will be large errors in your readings.

CONTINUITY TESTS

The ohmmeter is a convenient instrument to use in determining whether or not you have a continuous circuit. In lighting circuits a break, or "open," is easily discovered—a light, or group of lights, go out. But in many other circuits, certain test measurements known as CONTINUITY TESTS



(A) (B)

Figure 35.—Continuity tests.

must be made to locate a break. In *A* of figure 35, you have an illustration of a simple test circuit for determining the CONTINUITY of a transformer winding. A pair of phones and a battery have been placed across the winding that is under test. If the winding is intact, you hear a click in the phones whenever the connection is made or broken. If there is a break in the winding, you do not hear a click. In *B* of figure 35, the same test circuit is used to detect a ground in the wiring. Here a click indicates a defect in the insulation between the iron core and the winding.

CHAPTER 6

CHARACTERISTICS OF CIRCUITS

WHY KNOW THEM?

Here's your big chance to outrank the bull in the china shop. Just start fooling with electrical circuits before you know what you're doing. After blowing out a lot of instruments, you'll probably end up by electrocuting your friends or hanging yourself in a tangle of wires.

In practical electrical work you seldom use a simple circuit. You connect most electrical devices in series, in parallel, or in series-parallel combinations. ECONOMY and EFFICIENCY are the reasons for the more complicated connections. With multiple circuits, you can use one source of electrical energy to operate devices requiring different voltages and currents.

Before you can tell what type of connections to make, you must have more information on the electrical characteristics of parallel and series circuits than has so far been given. You understand the general laws for voltage, current, and resistance in these circuits. Too high a voltage and too high a current will burn out devices, and, on too low a voltage, devices will not operate. It is possible

for you to connect devices properly and still not have them operate properly.

VOLTAGE IN PARALLEL CIRCUITS

For each circuit that you see in figure 36, there is a DIFFERENT voltage. Otherwise, the circuits are electrically the same.

In *A* of figure 36, you can readily see that each device is connected with the battery. ASSUME that the connecting wires have NO resistance, the SAME voltage is applied to each lamp, and a voltmeter placed across each lamp registers 2 volts. In *B*

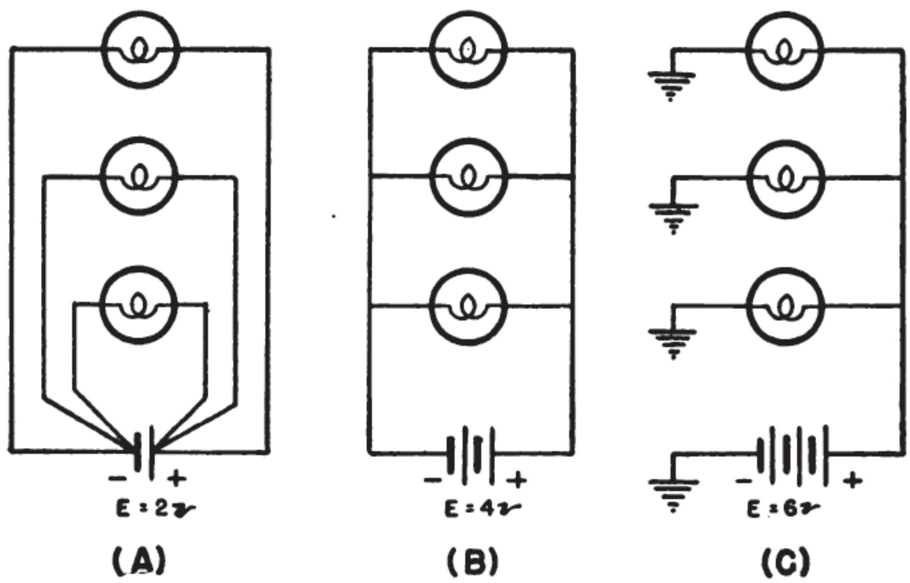


Figure 36.—Voltage in parallel circuits.

of figure 36, each lamp receives 4 volts. In *C* of figure 36, a voltmeter across each lamp reads 6 volts.

Here is the general law of VOLTAGE for parallel circuits—

IN ANY PARALLEL CIRCUIT, ALL DEVICES HAVE THE SAME VOLTAGE, or

$$E_T = E_1 = E_2 = E_3, \text{ etc.}$$

When—

E_T = Total voltage (battery voltage).

E_1 = Voltage across device No. 1.

E_2 = Voltage across device No. 2.

E_3 = Voltage across device No. 3.

CURRENT IN PARALLEL CIRCUITS

The number of paths for current in a parallel circuit is equal to the number of devices connected in the circuit.

In figure 37, you see the manner in which current divides in a conventional parallel circuit.

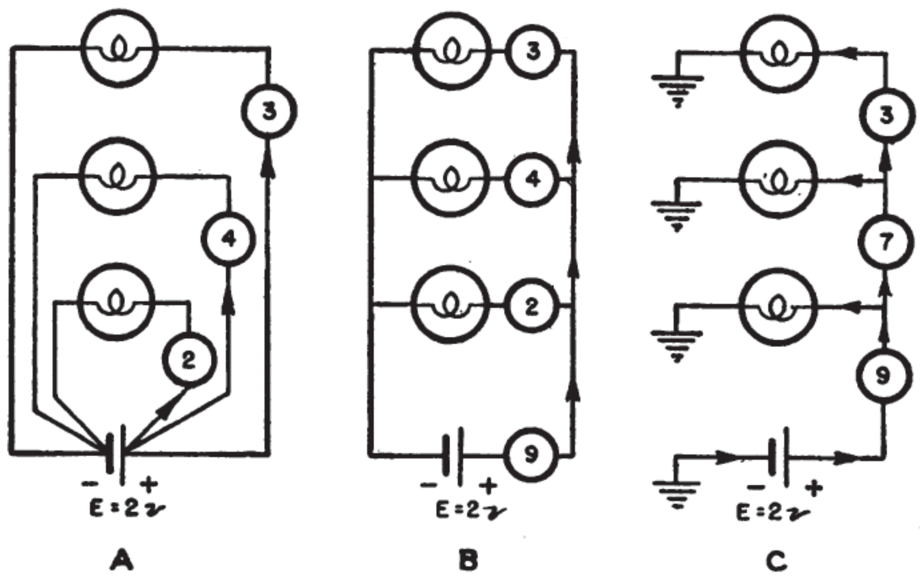


Figure 37.—Current in parallel circuits.

The ammeter readings show that the sum of the currents in the different branches of the circuit is equal to the battery current, or total current.

And here is the general law for CURRENT in parallel circuits—

IN ANY PARALLEL CIRCUIT, THE TOTAL CURRENT IS THE SUM OF THE CURRENTS IN THE SEPARATE BRANCHES, or

$$I_T = I_1 + I_2 + I_3, \text{ etc.}$$

When—

I_T = Total current.

I_1 = Current through device No. 1.

I_2 = Current through device No. 2.

I_3 = Current through device No. 3.

In figure 37, the lamps have the same voltage. BUT the currents through the different lamps are different because the lamps have different resistances. If all the lamps had the same resistance, the currents through them would be equal.

RESISTANCE IN PARALLEL CIRCUITS

Here's one to stump you. THE MORE THE RESISTANCES, THE LESS THE TOTAL RESISTANCE. How

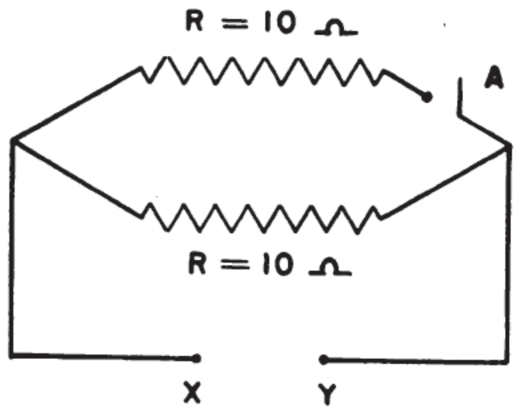


Figure 38.—Total resistance—parallel circuit.

come? In figure 38, note two resistors connected in parallel. Each resistor ALONE has a resistance of 10 ohms. When the switch at *A* is open, the resistance between points *X* and *Y* is 10 ohms. Close switch *A*, and you close a circuit in which the two resistors are in parallel. Now the TOTAL resistance between points *X* and *Y* is only 5 ohms, because you have provided a second path for the current. A large conductor offers less resistance than a small conductor of the same length. So

the two resistors are two conductors which together act like ONE larger conductor.

In all cases, when you provide more paths for current, you reduce the total resistance. The greater the number of resistances, or resistors, in parallel, the LOWER the TOTAL resistance. And, in EVERY instance, the combined resistance, or total resistance, of a parallel circuit is LOWER THAN the resistance of ANY INDIVIDUAL BRANCH.

Now wait a minute! Remember what the RECIPROCAL of a number is? It's 1 divided by the number. Thus the reciprocal of 3 is 1 divided by 3, or 1/3. The reciprocal of 4/5 is 1 divided by 4/5, and this equals 5/4. So the reciprocal of a fraction is the fraction inverted.

This brings you to the general law for resistance in parallel circuits.

IN ANY PARALLEL CIRCUIT, THE RECIPROCAL OF THE TOTAL RESISTANCE IS EQUAL TO THE SUM OF THE RECIPROCALS OF THE INDIVIDUAL RESISTANCES, or

$$1/R_T = 1/R_1 + 1/R_2 + 1/R_3, \text{ etc.}$$

When—

R_T = Total resistance in ohms.
R_1 = Resistance of resistor No. 1.
R_2 = Resistance of resistor No. 2.
R_3 = Resistance of resistor No. 3.

FOR INSTANCE—

What is the total resistance of a parallel circuit consisting of 4 resistors with resistances of 1, 2, 3, and 6 ohms, respectively?

$$\begin{aligned} 1/R_T &= 1/1 + 1/2 + 1/3 + 1/6. \\ &= 12/12 + 6/12 + 4/12 + 2/12. \\ &= 24/12. \\ 1/R_T &= 2. \\ R_T &= 1/2. \end{aligned}$$

IF ALL DEVICES, or resistors, in a parallel circuit have the SAME resistance, you can use a simpler formula. Divide the resistance of ONE device, or resistor, by the number of devices, or resistors, and you get the total resistance, or

$$R_T = R/N$$

When—

R_T = Total resistance.

R = Resistance of one device.

N = Number of devices.

FOR INSTANCE—

If three 10-ohm resistors are connected in parallel, what is the total resistance?

$R_T = R/N.$

$R_T = 10/3.$

$= 3\ 1/3.$

VOLTAGE IN SERIES CIRCUITS

In A of figure 39, you have a voltmeter and a simple circuit. ASSUME that the connecting wires have no resistance. Connect the voltmeter across the load resistor terminals, and you get a reading of the TOTAL VOLTAGE, which is 6 volts. Connect the voltmeter across HALF the total resistance, as in B of figure 39, and you get a reading of HALF as much voltage, or 3 volts. If you place the voltmeter across a THIRD of the total resistance, as in C of figure 39, you have a reading of 2 volts, or one third of the total voltage.

The voltage across any fraction of a resistance is the same fraction of the total voltage.

In A of figure 40, three equal SERIES resistors are connected to a 6-volt source. In the case of

each resistor, a voltmeter connected across it reads 2 volts.

In *B* of figure 40, you have a 4-ohm resistor in series with a 12-ohm resistor. The total resist-

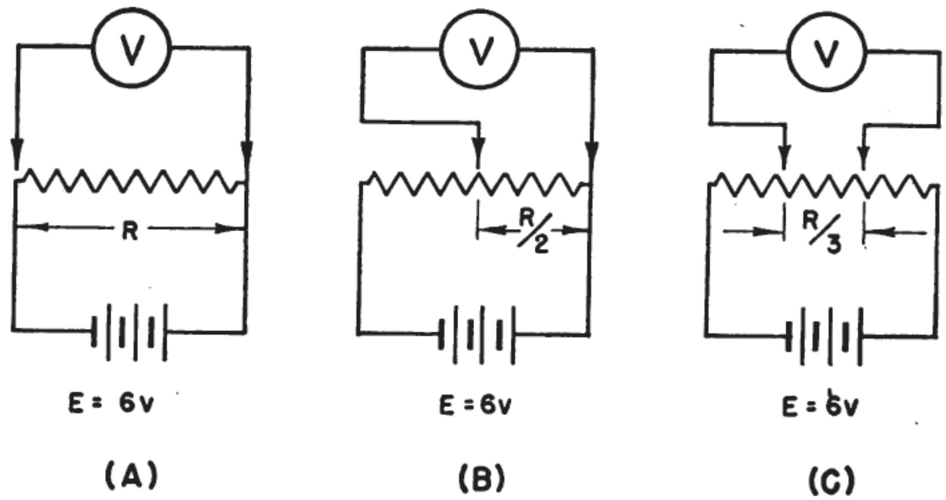


Figure 39.—Voltage across a resistance and fractions of the resistance.

ance of the circuit is 16 ohms. The 4-ohm resistor is $^4/_{16}$, or $^1/_4$ of the total resistance, and the voltage across it is $^1/_4$ of 12, or 3 volts. The

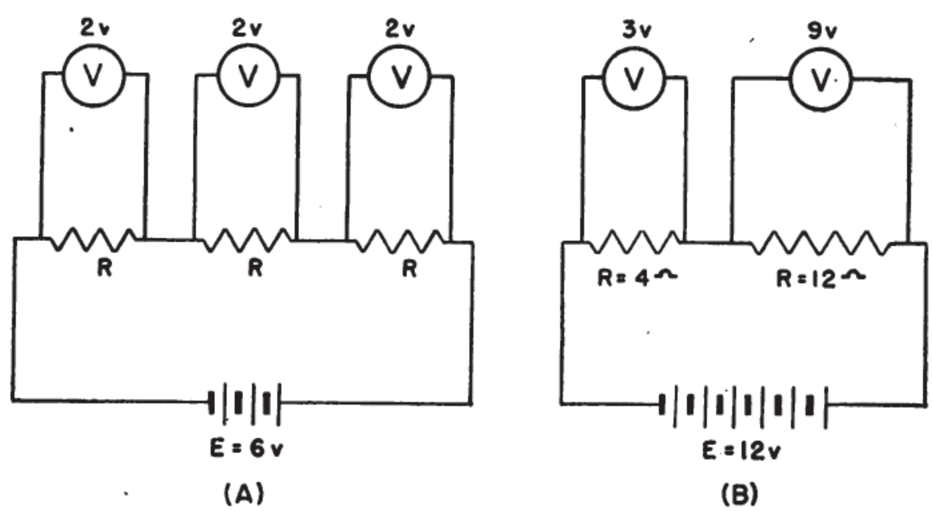


Figure 40.—Voltage distribution—series circuit.

12 ohm resistor is $^{12}/_{16}$ or $^3/_4$ of the total resistance, and the voltage across it is $^3/_4$ of 12 or 9 volts.

In both *A* and *B* the voltages across the devices add up to the total voltage.

The general law of VOLTAGES for series circuits—

IN ANY SERIES CIRCUIT, THE SUM OF THE VOLTAGES ACROSS THE DIFFERENT PARTS IS EQUAL TO THE TOTAL VOLTAGE, or

$$E_T = E_1 + E_2 + E_3, \text{ etc.}$$

E_T = Total voltage.

E_1 = Voltage across resistor No. 1.

E_2 = Voltage across resistor No. 2.

E_3 = Voltage across resistor No. 3.

CURRENT IN SERIES CIRCUITS

There is only one path for current in a series circuit, and the number of electrons passing any point in the circuit is the same as the number passing any other point of the circuit.

Now, here is the general law for CURRENT in series circuits. **THE CURRENT VALUE, OR AMPERAGE, IS THE SAME FOR ALL PARTS OF A SERIES CIRCUIT,** or—

$$I_T = I_1 = I_2 = I_3, \text{ etc.}$$

When—

I_T = Total current.

I_1 = Current through resistor No. 1.

I_2 = Current through resistor No. 2.

I_3 = Current through resistor No. 3.

RESISTANCE IN SERIES CIRCUITS

In figure 41, you see two resistors in series. Note that, in passing from *A* to *C*, the current meets twice as much "opposition," or resistance as in passing from *A* to *B*. There is only one

path for the current and two resistors in turn resist the flow. Similarly, every device, or resistor, IN SERIES with other devices, or resistors, plays its part in opposing flow of current.

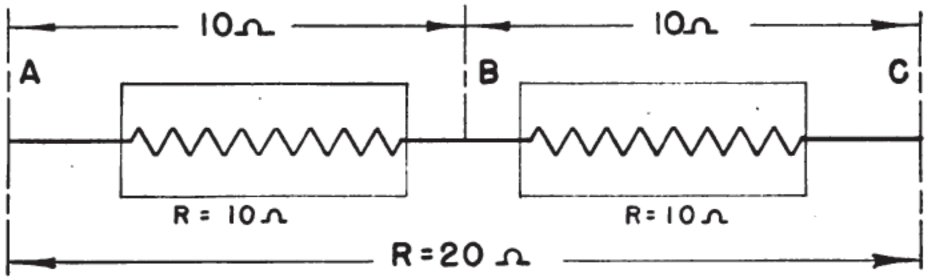


Figure 41.—Resistance in series circuits.

And this is the general law for RESISTANCE in series circuits.

IN ANY SERIES CIRCUIT, THE TOTAL RESISTANCE IS EQUAL TO THE SUM OF THE INDIVIDUAL RESISTORS, or

$$R_T = R_1 + R_2 + R_3, \text{ etc.}$$

When—

R_T = Total resistance in ohms.

R_1 = Resistance of resistor No. 1.

R_2 = Resistance of resistor No. 2.

R_3 = Resistance of resistor No. 3.

GENERAL LAWS FOR SERIES AND PARALLEL CIRCUITS

	Voltage	Current	Resistance
Series	Total voltage equals sum of voltage across the parts— $E_T=E_1+E_2+E_3$, etc.	Current is the same in all parts— $I_T=I_1=I_2=I_3$, etc.	Total resistance equals sum of resistance of parts— $R_T=R_1+R_2+R_3$, etc.
Parallel	Voltage is the same in all parts of the circuit— $E_T=E_1=E_2=E_3$, etc.	The total current equals sum of the current in the different parts— $I_T=I_1+I_2+I_3$, etc.	The total resistance is less than the lowest resistance in the circuit— $\frac{1}{R_T}=\frac{1}{R_1}=\frac{1}{R_2}+\frac{1}{R_3}$, etc.

Don't try to break the law. You can't. Rush bullheadedly smack into Ohm's Law and all you get is a broken head. Ohm's Law states how *I,*

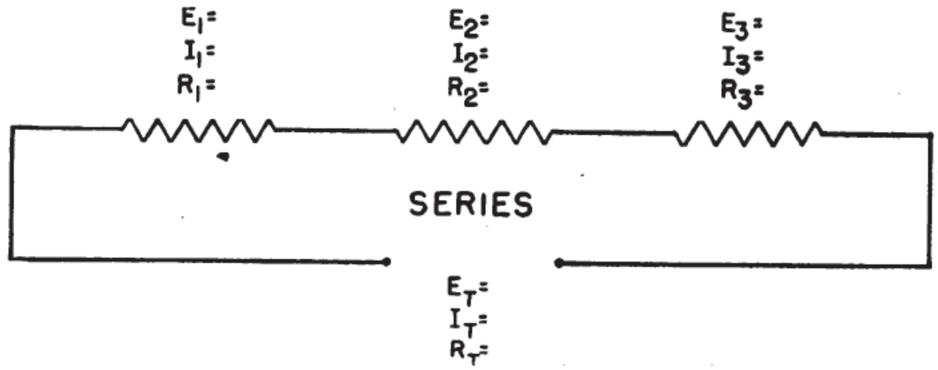


Figure 42.—Problem pattern—series circuit.

E, and *R* must be related in every electrical circuit.

You will find that a little thought is necessary to solve Ohm's Law problems involving parallel and series circuits. You have to consider division of current, distribution of voltage, and ar-

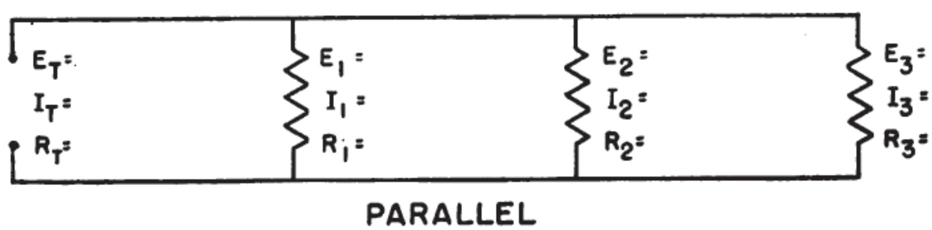


Figure 43.—Problem pattern—parallel circuit.

rangement of resistance in the various parts of circuits. You must know not only Ohm's law but also the general laws of voltage, current, and resistance in parallel and series circuits.

To solve problems involving Ohm's Law in parallel and series circuits, you will find it helpful to set up the problems according to the patterns you see in figures 42 and 43.

FIRST, you put down all the KNOWN VALUES in their correct places in the pattern.

THEN, by obeying Ohm's Law and the general laws for series and parallel circuits, you can find the UNKNOWN VALUES.

Suppose two 10-ohm resistors and one 20-ohm resistor are placed in series across a potential source of 80 volts. Can you find the current through each resistor and the voltage applied to it?

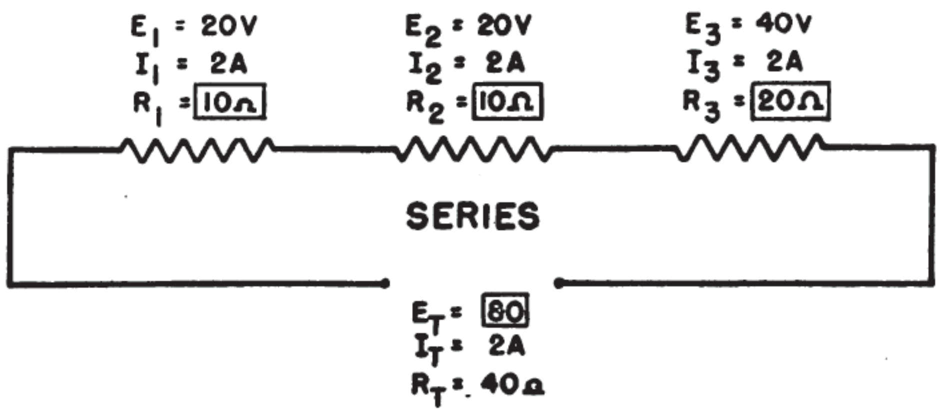


Figure 44.—Sample calculation diagram.

First, the known values are placed in their correct positions on the problem diagram. They are indicated by the values enclosed in rectangles. Unknown values are added to the diagram as they are computed. See figure 44.

1. $R_T = R_1 + R_2 + R_3$.
   $R_T = 10 + 10 + 20 = 40$—
2. $I = \frac{E_T}{R} = \frac{80}{40} = 2$ amperes.

This total current exists in all parts of the circuit. It is therefore substituted in three positions on the diagram.

3. $E_1 = I_1 \times R_1$. $\quad E_2 = I_2 \times R_2$. $\quad E_3 = I_3 \times R_3$.
   $2(10) = 20$ v. $\quad 2(10) = 20$ v. $\quad 2(20) = 40$ v.

The voltage across the parts adds up to the total voltage.

Suppose three vacuum tubes, each rated at 0.3 amperes at 6.3 volts are to be connected in series and operated from a 110-volt source by the use of current limiting resistor placed in series with the

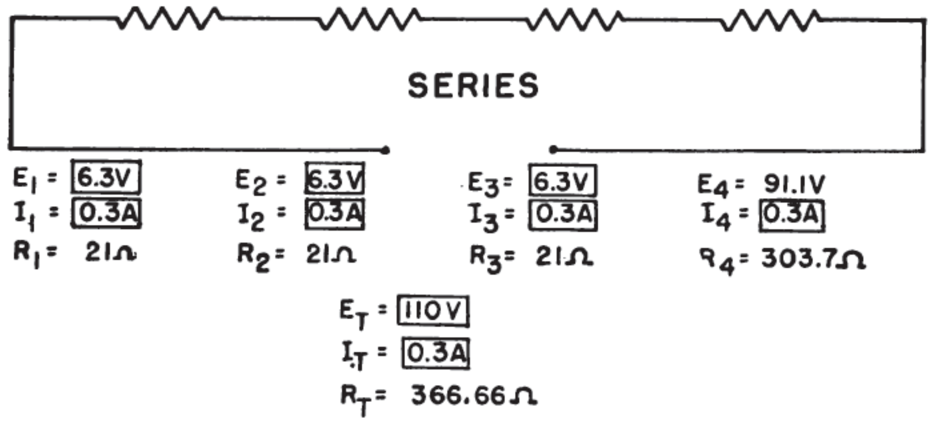


Figure 45.—Another sample calculation diagram.

tubes. What resistance value would be used for this limiting resistor?

Since this is a series circuit, the current in all parts of the circuit is 0.3 amperes. Hence $I_T=0.3$ and $I_4=0.3$ amperes.

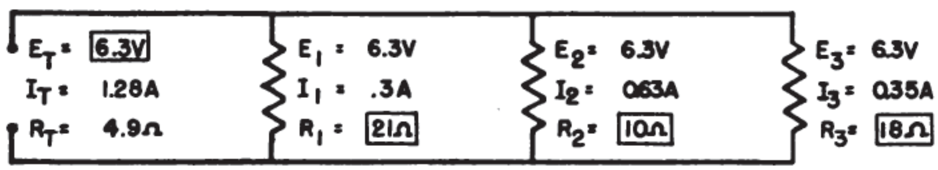
1. $R_T=\frac{E_T}{I_T}=\frac{110}{0.3}=366.66.$
2. $R_1=\frac{E_1}{I_1}=\frac{6.3}{0.3}=21.$
3. $E_T=E_1+E_2+E_3+E_4.$
   $110=\ 6.3+6.3+6.3+E_4.$
   $110=18.9+E_4.$
   $110=18.9=E_4.$
   $91.1=E_4.$
4. $R=\frac{E}{I}=\frac{91.1}{0.3}=303.7.$

This is the answer to the problem.

5. $R_T = R_1 + R_2 + R_3 + R_4.$
$366.66 = 21 + 21 + 21 + R_4.$
$366.66 = 63 + R_4.$
$366.66 - 63 = R_4.$
$303.66 = R_4.$

This is a check to show the answer is right.

Suppose three vacuum tubes with resistance values of 21, 10 and 18 ohms are connected across a 6.3 volt supply. Can you find the current to each tube, the total current, total voltage and total resistance of the circuit?



PARALLEL

Figure 46.—Still another sample calculation diagram.

1. $E_T = E_1 = E_2 = E_3$ etc.
2. $I_1 = \frac{E_1}{R_1} = \frac{6.3}{21} = 0.3$ amperes.

$I_2 = \frac{E_1}{R_1} = \frac{6.3}{10} = .63$ amperes.

$I_3 = \frac{E_3}{R_3} = \frac{6.3}{18} = .35$ amperes.

3. $I_T = I_1 + I_2 + I_3.$

$= 0.3 + 0.63 + 0.35 = 1.28$ amperes.

4. $R_T = \frac{E_T}{I_T} = \frac{6.3}{1.28} = 4.9.$

This is the answer.

5. $\frac{1}{R_T}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}.$

$$\frac{1}{R_T}=\frac{1}{21}+\frac{1}{10}+\frac{1}{18}.$$

$$=0.0476+0.10+0.0555.$$

$$=0.2031$$

$$=\frac{1}{0.2031}=4.9—$$

This is the check.

When you have followed through the solutions of each of these problems and have examined the correct answers, go back over each step in the solutions. Check and double check to be sure you understand them. Then set up the schematic pattern for each problem on a separate sheet of paper. Put down the known values. Then see if you can find the unknown values without reference to the text.

VOLTAGE DROP

In studying the general laws for voltage in parallel and series circuits, you assume that connecting wires offer no resistance. This assumption is not actually true. It was made merely to simplify your introduction to the general law for voltage in series circuits.

Actually, the connecting wires of any circuit do offer a certain amount of resistance. A certain amount of the applied voltage is used up forcing the current through the connecting wires. This loss of voltage is referred to as voltage drop.

In most cases, the voltage drop is so small, you can assume it does not exist. However, when the load resistance is low, the resistance of the con-

necting wires becomes an appreciable part of the total resistance. This makes it necessary to make allowance for voltage drop.

If you assume that a simple circuit has no resistance in the connecting wires, you will have a diagram such as you see in (*A*) of figure 47.

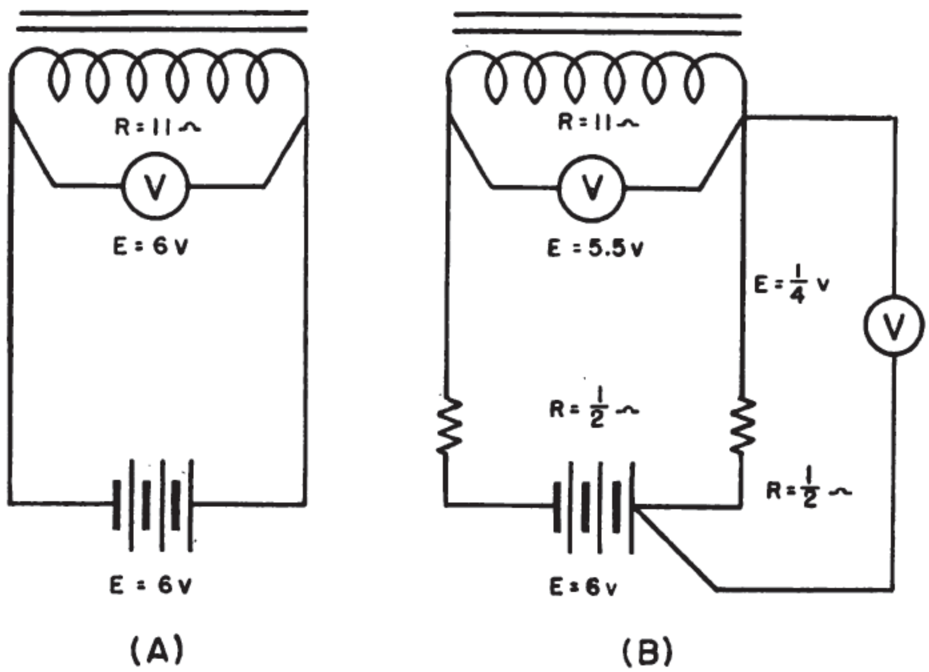


Figure 47.—Voltage drop.

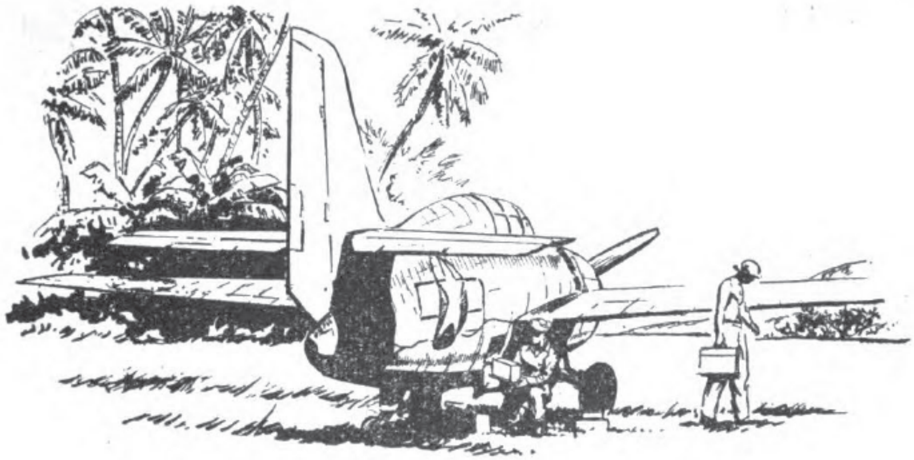
Assuming this, the voltage across the coil will be equal to the battery voltage.

But if you make the actual allowance for the resistance of the connecting wires, you will have a diagram such as you see in (*B*) of figure 47. Here, the two resistors represent the resistance of the connecting wires. What you actually have in (*B*) is a series circuit.

Now, as you know, each individual part of a series circuit that has any resistance will have a fraction of the total voltage applied to it. The voltage across any particular part is used to force current through that particular part.

So, with the voltage and resistance values indicated in (*B*) of figure 47, an application of Ohm's Law will show that ¼ volt exists across each connecting wire. A low reading voltmeter connected at the proper points will show the same result. You have a voltage drop of ¼ volt.

Voltage drop is proportional to the resistance of the connecting wires. You can calculate the voltage drop across any circuit part by applying Ohm's Law.



CHAPTER 7

CIRCUIT RESISTANCE

FIVE FACTORS

Circuit resistance means total resistance of a circuit. In any circuit, five factors contribute to total resistance.

The NUMBER AND TYPE of devices acting as a load circuit.

The ARRANGEMENT of these devices.

The RESISTANCE of switching devices.

The RESISTANCE of CONNECTING WIRES.

The INTERNAL resistance of the VOLTAGE SOURCE.

The most important factors in determining circuit resistance are the number and type of devices acting as a load circuit, and the arrangement of these devices. In figure 48, you have a comparison of the circuit resistance offered by three 6–ohm resistors when they are connected in series, parallel, and series-parallel.

You can disregard the resistance of switching devices, connecting wires, and the voltage source when THESE FACTORS MAKE UP SO SMALL A PART OF THE CIRCUIT RESISTANCE THAT YOU CAN NEGLECT

THEM. But, THE RESISTANCE OF CONNECTING WIRES IS A SIGNIFICANT PART of the total resistance WHEN THE LOAD RESISTANCE IS LOW. For instance, the starter motor circuit in automobiles and airplanes is a low-resistance load circuit, and successful operation depends on the wires used to make connections.

The resistance of connecting wires depends on—

The MATERIAL out of which the wires are made;

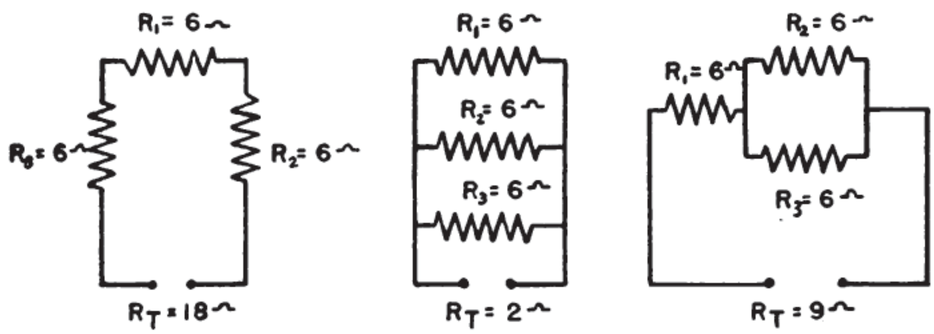


Figure 48.—Total circuit resistance.

the LENGTHS of the wires; the CROSS-SECTIONAL area of the wires; and the TEMPERATURE of the wires.

MATERIAL AND LENGTH

Silver is the best conductor. It offers the least resistance. Next in order are copper and aluminum. Silver, however, is seldom used because of the cost. Copper is almost as good, is relatively inexpensive, and so it serves for most types of wiring. Aluminum is used where weight is an important factor. Certain heating devices and other electrical appliances incorporate "resistance" wire, made of various high-resistance alloys.

The resistance of any conductor is directly proportional to its length. Double the length and you double the resistance. Triple the length and you triple the resistance.

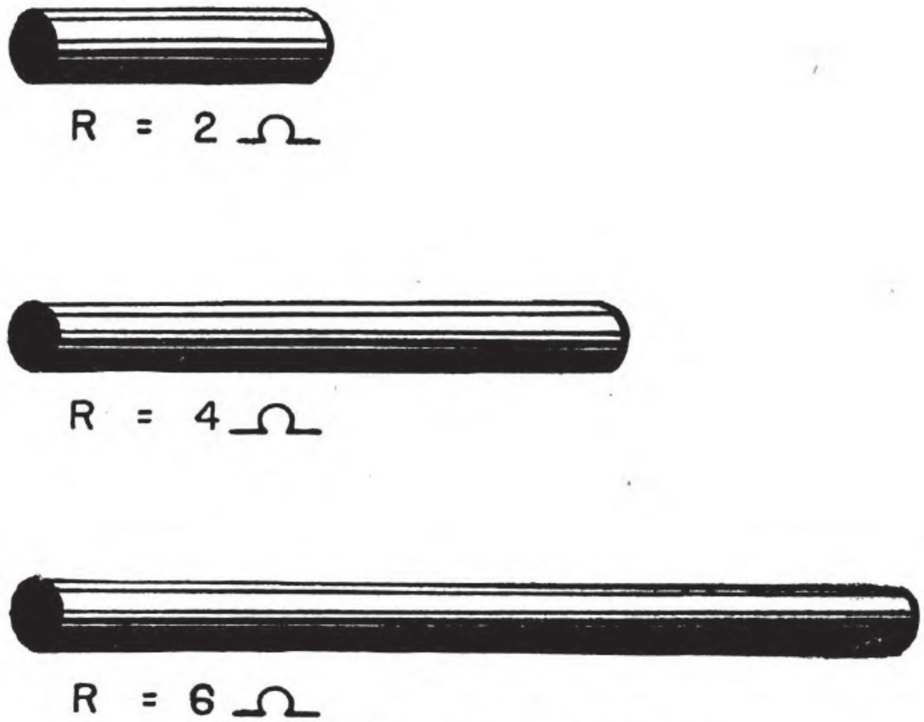


Figure 49.—Effect of length on resistance.

CROSS-SECTIONAL AREA (C. S. A.)

Cross-sectional area, or C. S. A., is the area of a section cut through an object. The cross-

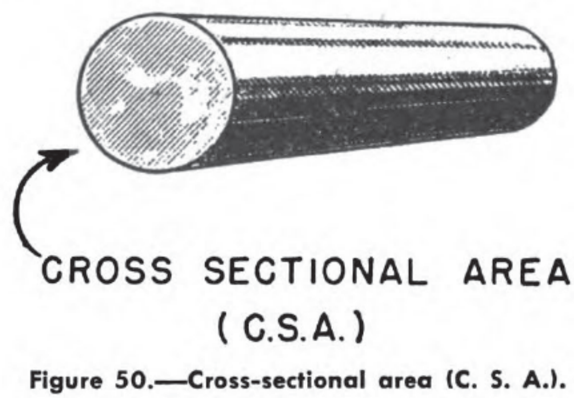


Figure 50.—Cross-sectional area (C. S. A.).

sectional area of a wire is the amount of surface on the end of a wire cut at right angles to the axis of the wire. In figure 50, the shaded section is the cross-sectional area.

The larger the conductor, the less the resistance—the easier it is to set up a great flow of

electrons, or current. In more precise terms, THE RESISTANCE OF A CONDUCTOR is inversely PROPORTIONAL TO ITS CROSS-SECTIONAL AREA.

Suppose the copper bar in (*A*) of figure 51 has a resistance of 8 ohms, and the copper bar in (*B*) has the same length but double the C. S. A. Then the bar in (*B*) will have one-half the resistance of the bar in (*A*), or 4 ohms. The bar in (*C*)

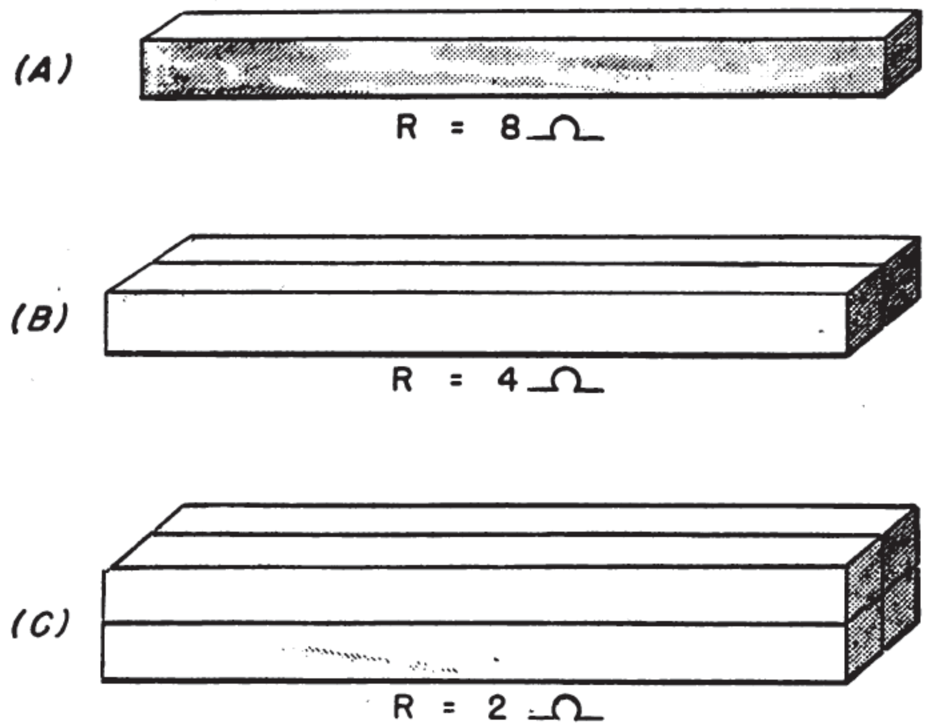


Figure 51.—Resistance and cross-sectional area.

has four times the C. S. A. of the bar in (*A*), and its resistance is—well, what is it? Right you are! Only 2 ohms.

Now, except in certain types of transformers, SQUARE conductors are rarely used. Most electrical conductors are circular, and so you must learn the trick of dealing with the resistances of circular cross-sectional areas.

Suppose the conductor in (*A*) of figure 52 has a resistance of 10 ohms and is 1 inch in diameter. Suppose the conductor in (*B*) is of the same

length (and material, too, of course) but has twice the diameter of the wire in (A)—that is, a diameter of 2 inches. Has the conductor in (B) twice the C. S. A. of the wire in (A) and so one-half the resistance? No. Actually, the wire in (B) has only one-fourth the resistance of the wire

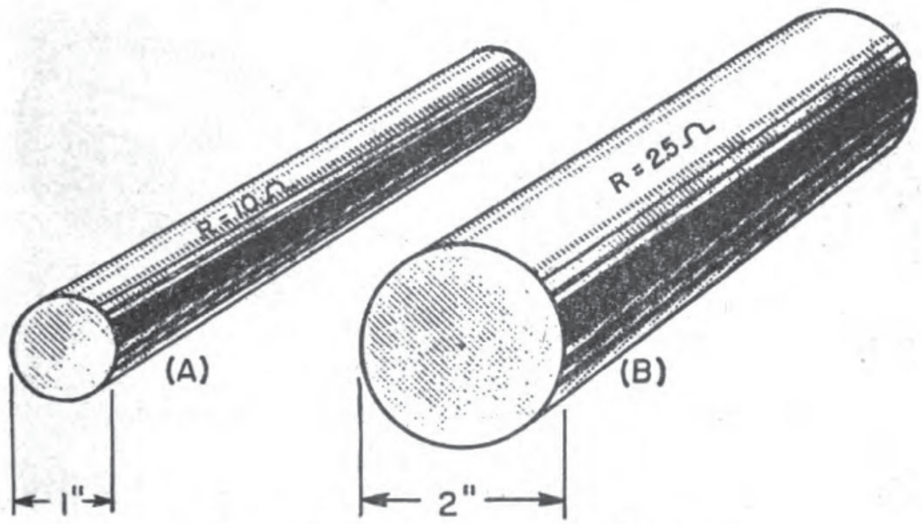


Figure 52.—Effect of doubling diameter.

in (A), because (B) has FOUR TIMES as much C. S. A.

How come? Well, the two circles in (A) and (B) have diameters that are in the ratio of 2 to 1.

$$(A)$$

$$\text{Area} = 0.7854\ (d^2) = 0.7854\ (1)^2.$$

$$A_1 = 0.7854 \text{ square inches.}$$

$$(B)$$

$$A_2 = 0.7854\ (d^2) = 0.7854\ (2)^2.$$

$$= 0.7854\ (4) \text{ square inches.}$$

$$\frac{A_2}{A_1} = \frac{0.7854(4)}{0.7854} = 4$$

The C. S. A. of the wire in (B) is four times the C. S. A. of the wire in (A).

The area of a circle varies with the square of its diameter, and the resistance of an ordinary conductor varies INVERSELY with the square of its diameter.

In figure 53 you can see the relationship between C. S. A. and resistance for three conductors

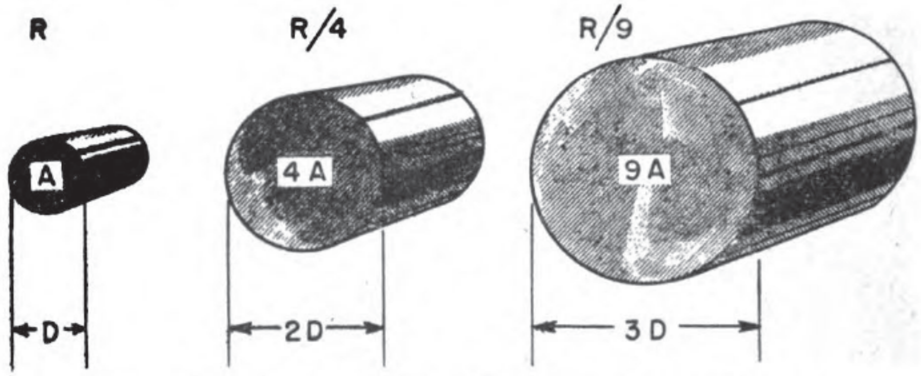


Figure 53.—Relationship—C. S. A., current, and resistance.

of the same material and length when the diameters are multiples of each other.

CIRCULAR MIL AREA

You rarely express the cross-sectional area of electrical conductors in square inches. Instead,

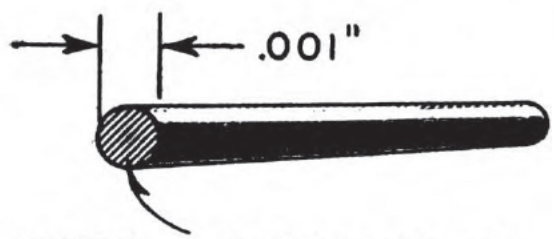


Figure 54.—Circular mil area.

you use the standard unit of measurement for conductor area, the CIRCULAR MIL. As you see in figure 54, a circular mil is the cross-sectional area of a wire $\frac{1}{1000}$ (0.001) inch in diameter.

B. and S. gage	Diameter in mils (d)	Area in circular-mils (d^2)	Ohms per 1,000 feet at 20° C. or 68° F.
1	2	3	4
0000	460.00	211,600	0.04893
000	409.64	167,810	.06170
00	364.80	133,080	.07780
0	324.86	105,530	.09811
1	289.30	83,694	.1237
2	257.63	66,373	.1560
3	229.42	52,634	.1967
4	204.31	41,742	.2480
5	181.94	33,102	.3128
6	162.02	26,250	.3944
7	144.28	20,816	.4973
8	129.49	16,509	.6271
9	114.43	13,094	.7908
10	101.89	10,381	.9972
11	90.742	8,234.0	1.257
12	80.808	6,529.9	1.586
13	71.961	5,178.4	1.999
14	64.084	4,106.8	2.521
15	57.068	3,256.7	3.179
16	50.820	2,582.9	4.009
17	45.257	2,048.2	5.055
18	40.303	1,624.3	6.374
19	35.890	1,288.1	8.038
20	31.961	1,021.5	10.14
21	28.462	810.10	12.78
22	25.347	642.40	16.12
23	22.571	590.45	20.32
24	20.100	404.01	25.63
25	17.900	320.40	32.31
26	15.940	254.10	40.75
27	14.195	201.50	51.38
28	12.641	159.79	64.79
29	11.257	126.72	81.70
30	10.025	100.50	103.0
31	8.928	79.70	129.9
32	7.950	63.21	163.8
33	7.080	50.13	206.6
34	6.305	39.75	260.5
35	5.615	31.52	328.4
36	5.000	25.00	414.2
37	4.453	19.82	522.2
38	3.965	15.72	658.5
39	3.531	12.47	830.4
40	3.145	9.89	1,047

Figure 55.—B. & S. wire gage table.

How do you find the C. S. A. in circular mils for any conductor? You simply express the diameter of the wire in mils, and then square the number.

FOR INSTANCE—

Express in circular mils the C. S. A. of a wire 0.010″ in diameter.

$$0.010'' = 10 \text{ mils}$$
$$(10)^2 = 100 \text{ circular mils}$$

If you know the circular mil area of a conductor, it is easy for you to find the diameter.

FOR INSTANCE—

Find the diameter of a wire whose C. S. A. is 100 circular mils.

$$\sqrt{100} = 10 \text{ mils}$$
$$10 \text{ mils} = 0.010''$$

Conductor sizes are expressed by numbers in the American Wire Gage (B. & S.) tables. See figure 55 on the preceding page.

TEMPERATURE

Usually, the resistance of a circuit or conductor is constant and not dependent upon either current or voltage. But if the current is very high in a circuit, the temperature may rise and cause an increase in resistance. When hot, the filament of an incandescent lamp has a much higher resistance than when cold. Carbon is an exception. Its resistance decreases with a rise in temperature. Certain alloys such as manganin, an alloy of copper and manganese, maintain constant resistance through wide variations in temperature.

The flow of current through a conductor causes the production of heat within the conductor. The resultant rise in temperature sets a limit on the amount of current that can be passed through the conductor.

This heat radiates out into space or is conducted away through materials in contact with the conductor. If heat is produced faster than it is dissipated, the conductor may finally melt. Insulation

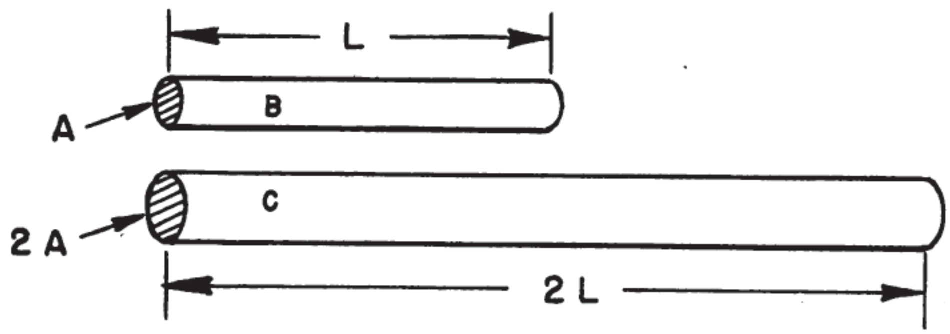


Figure 56.—Current-carrying capacity and heat dissipation.

on a conductor retards dissipation of heat. Hence a bare wire has a somewhat higher current-carrying capacity than a similar wire with insulation.

In figure 56, you have two conductors made of the same material. Conductor *C* has twice the length and twice the C. S. A. of conductor ***B,*** so the conductors have the SAME resistance. But conductor *C* has more total surface area—not C. S. A. —and can radiate away more heat, hence it can carry more current than conductor ***B***.

CHAPTER 8

CIRCUIT FAULTS

YOUR FAULT!

A circuit fault is your fault. Thats the moral of this chapter. What is a circuit fault? Some factor that causes a break in a circuit or otherwise cuts the required flow of current.

You must be alert to prevent circuit faults. You don't need to be psychic to foresee trouble. You need only to pay intelligent attention to your work. If trouble does develop unavoidably, you must know what to do. You must know, too, the safety precautions—and the reasons therefor, so you won't die of a misprint in some set of rules.

PROPER CONNECTIONS

A proper connection introduces no additional resistance into the circuit. You may make connections through binding posts, plugs, switches, re-

ceptacles, wire splices, spring contacts, clip leads, soldered joints, and lug connections.

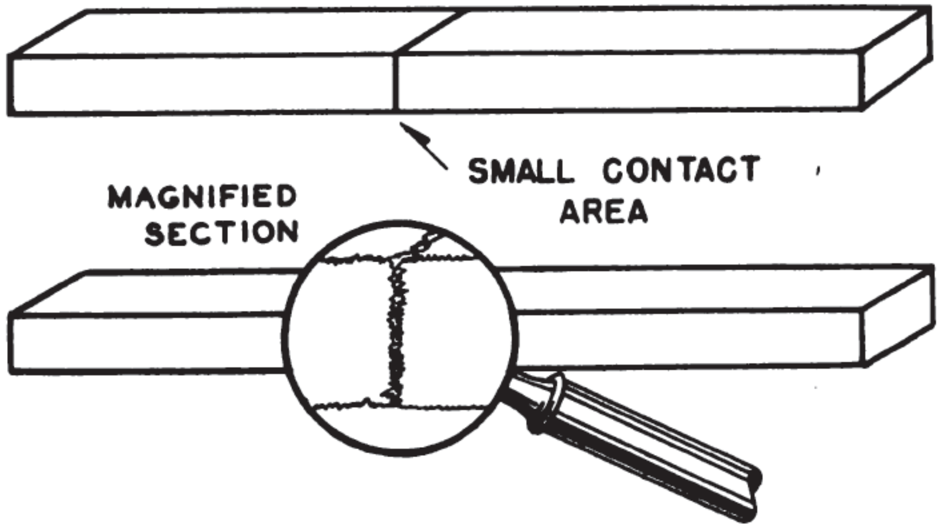


Figure 57.—Contact resistance.

A faulty connection introduces resistance into the circuit and so reduces the required flow of current. To go to an extreme—when you have a loose connection and no contact at all, you have introduced infinite resistance into the circuit—no current flows.

To insure low resistance, any connection between two conductors must have a comparatively large contact area. The area in contact should never be less than the cross-sectional area of the conductors forming the junction. Although conductor surfaces may appear smooth, they are really rough. Merely place two surfaces together and, as you see in figure 57, you provide a poor path for the current. It passes only from the high rough spots of one surface to the high rough spots of the other surface. You have high resistance at the contact. So you reduce the current and at the same time cause excessive heating. Have a look at figure 58 and note that contact resistance may be overcome by overlapping the conductors.

Wires should be joined by splicing. Don't depend on the small contact area available in a butt joint.

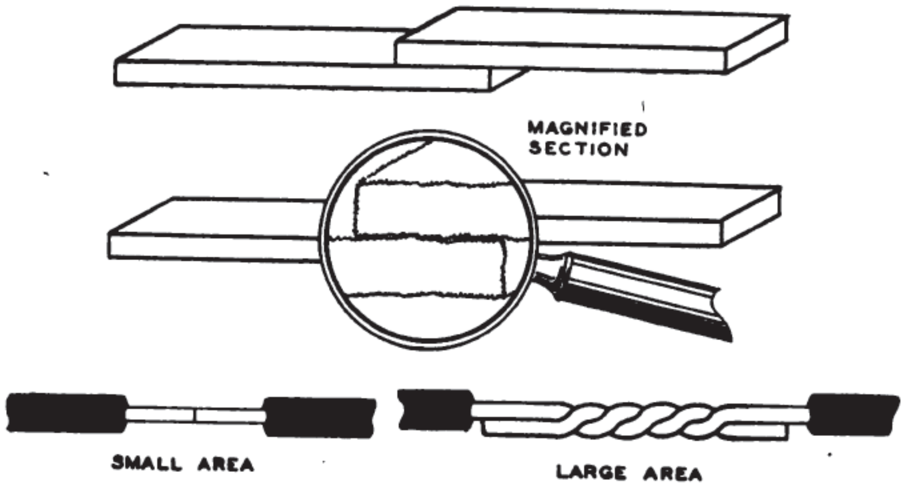


Figure 58.—Effect of increasing area.

LOOSE CONNECTIONS

In loose connections, such as you have in figure 59, the conductors touch only at certain spots. They produce small contact area, and a high resistance, decrease in current strength. In high voltage circuits, such loose contacts are dangerous. The current jumps the gap or arcs. In arcing, at the very least there is oxidation, or corrosion, and the connection continuously deteriorates.

Wherever there is vibration, as in airplanes, loose connections are especially serious. Vibration may break-make the circuit at the loose connection and cause an unsteady flow of current to an important electrical unit.

Contrary to popular opinion, electrical units in ordinary circuits—with a single source of voltage—do NOT burn out because of loose connections. A loose connection causes a DECREASE in current flow. "Burnouts" usually result from EXCESSIVE current, from lack of voltage control. Still, loose connections injure insulation and are fire hazards.

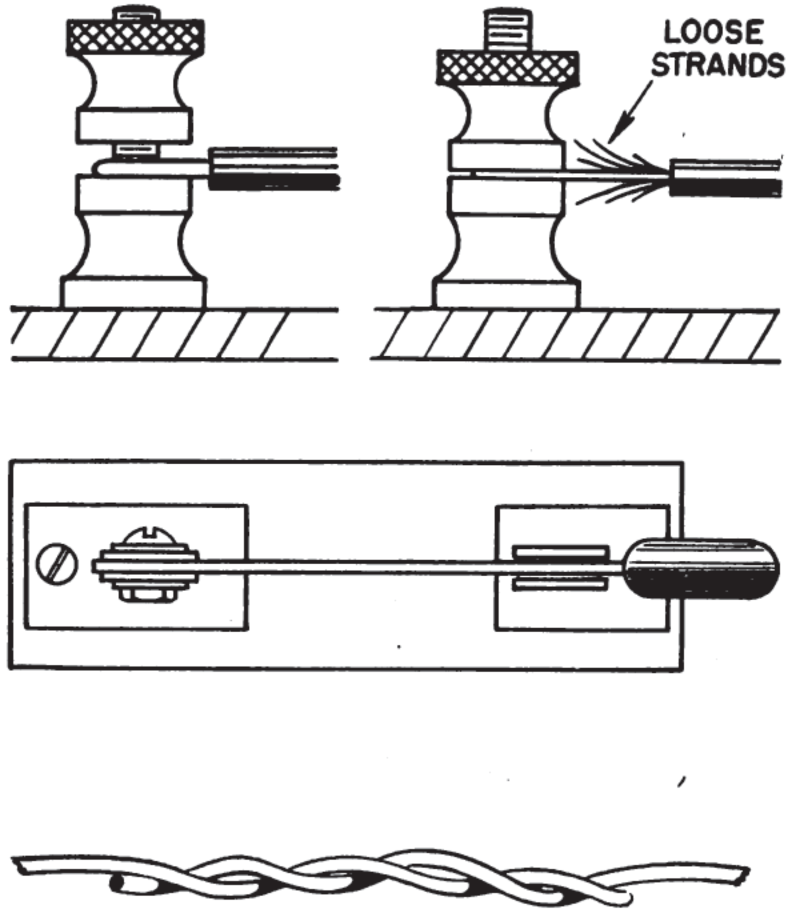


Figure 59.—Loose connections.

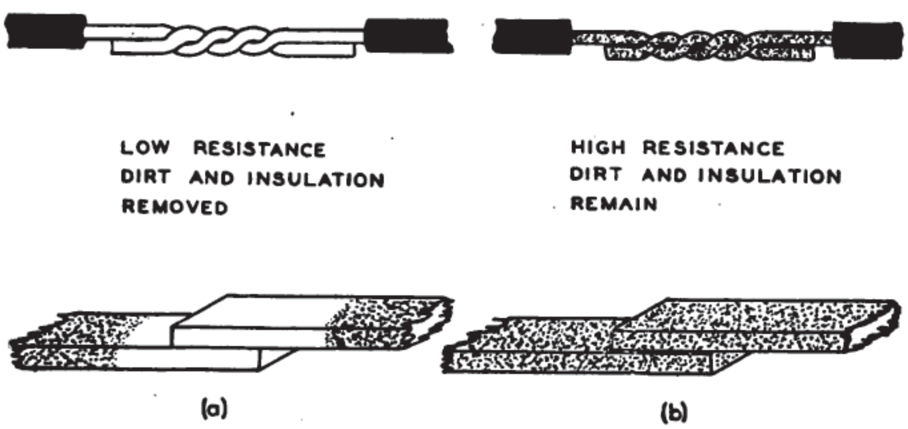


Figure 60.—Dirty contacts.

DIRTY CONTACTS

The surfaces of two conductors in a connection should be clean. Obviously, surfaces covered with foreign matter make poor electrical connections. Observe, in figure 60, how dirt causes a high resistance layer between the conductors. For low resistance—a clean connection.

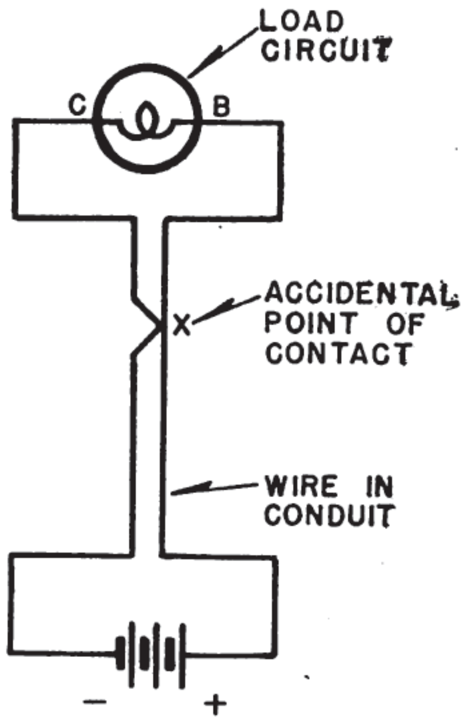


Figure 61.—Short circuit.

SHORT CIRCUITS

Often the voltage source for a circuit is some distance from the load circuit, and a pair of leads is used to complete the circuit. The wires in the pair are usually located close to each other—and if the insulation should be destroyed, the conductors may make contact, or SHORT CIRCUIT. You can regard a short circuit as an "additional" circuit accidentally made—and of such LOW RESISTANCE that excessive current flows.

In figure 61, the circuit normally has only one path for current. This path is, of course, the load circuit itself. If the wires touch at (X), then two paths for current exist. One is through the load circuit (+, *B, D,* −). The other is through the short (+, *X,* −).

The current to each path depends on the resistance of each path, and the voltage acting on it. Both paths have the same voltage. But the short circuit has practically no resistance. So, a very high current flows through the short. The high

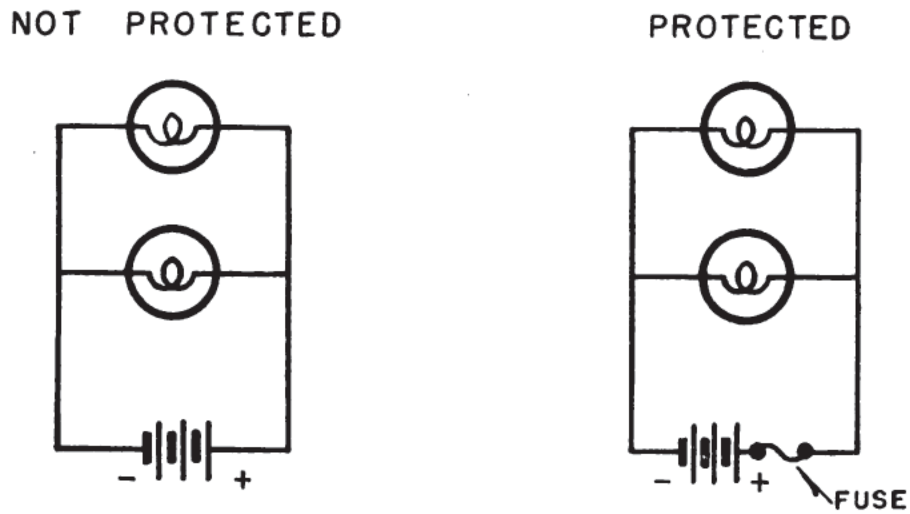


Figure 62.—Fusing—ungrounded circuits.

temperature developed by the high current may melt the wires or start a fire.

The remainder of the circuit (*X, B, C, X*) may not be damaged. But current flow through it will cease when either wire in the shorted section melts.

FUSES

A fuse is used to protect a circuit from short circuits and overloads. This device has a metallic element with a low melting point. It is inserted in series with a circuit, as you see in figure 62. An excessive current melts the low-melting

element and breaks the circuit before damage is done other parts of the circuit.

The most common types of fuses are the plug type, such as you find in homes, and the cartridge type, such as you find in airplanes, automobiles, main line switches.

Fuses are RATED IN AMPERES, because a fuse is used to limit the current, or amperes, in a circuit. Thus a 10-ampere fuse limits the current in a circuit to a maximum of 10 amperes. Greater amperage "blows" the fuse.

Common sense tells you that, in replacing a fuse, you must use one having the same ampere

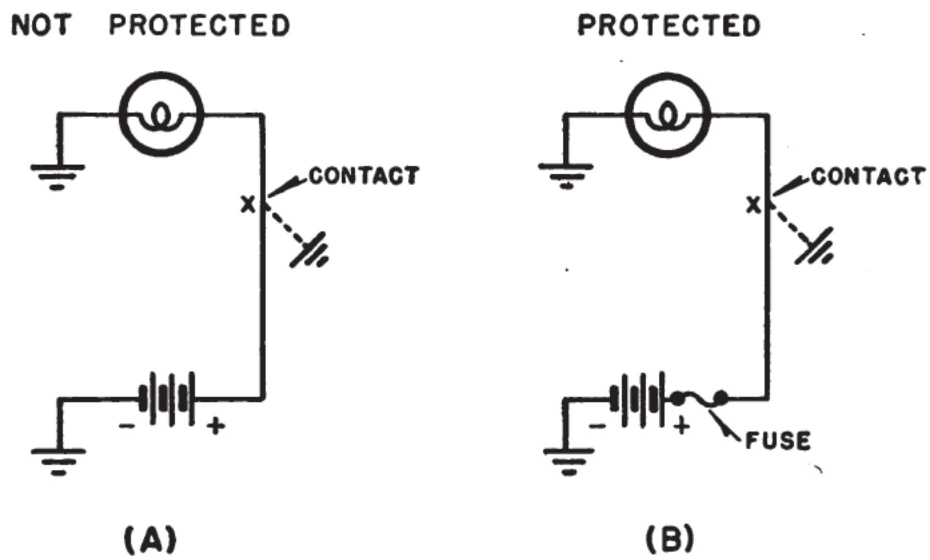


Figure 63.—Fusing—grounded circuits.

rating. A 20-ampere fuse does not protect a circuit with a 10-ampere limit.

In (*A*) of figure 63, you can note that an accidental ground at any point from the battery terminal to the connection on the lamp will cause a short circuit. The conditions relating to short circuits, overloading, and fusing relate also to grounded circuits. The wire section from the battery to the accidental ground carries the full short circuit current, and you have the same dam-

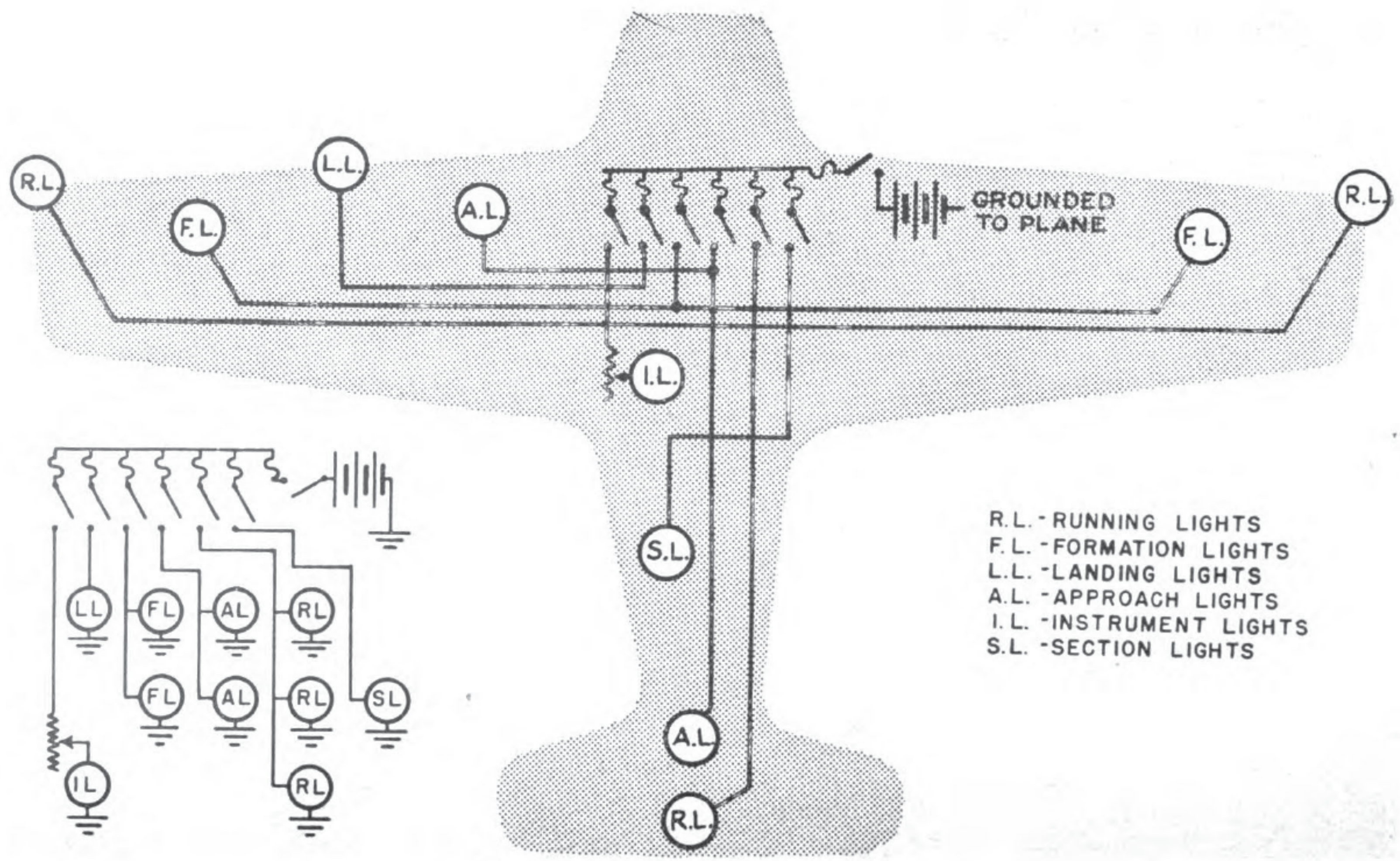


Figure 64.—Lighting system schematic.

age and fire hazards as with an ungrounded circuit. Add a fuse, as in (*B*) of figure 63, to protect this grounded circuit.

In circuits where you have several devices that are operated from one voltage source, it is often desirable to have a fuse for each device. For, if only one main fuse is used, a short anywhere in the circuit halts current flow to all devices. When you have individual fuses, the short is localized and only one device may be put out of operation. In most circuits, you have a combination of main and branch fuses, such as you

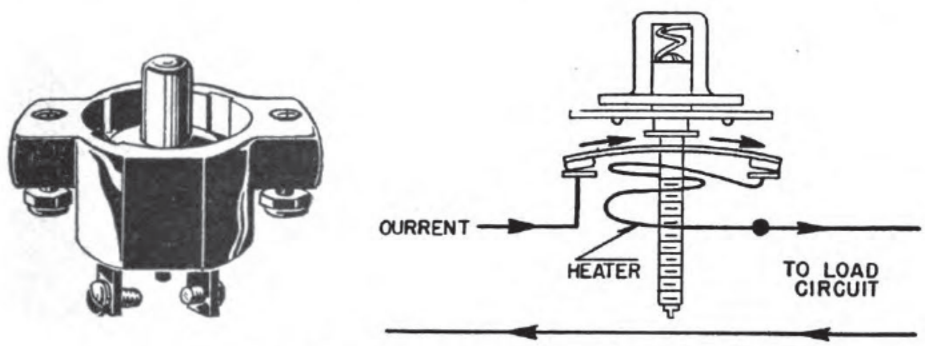


Figure 65.—Thermal type circuit breaker.

see in figure 64—a diagram of a conventional lighting circuit for an airplane with complete fusing.

THERMAL TYPE CIRCUIT

In airplanes electrical circuits are protected not only by fuses but also by thermal circuit-breakers of the type shown in figure 65. The current passes through a thin metal disk which bridges two contacts IN SERIES with a piece of resistance wire. The wire acts as a "heater." Whenever excessive current flows as a result of overloading or short circuit, the heat developed in the wire "heater" causes the disk to buckle into a horizontal position and to break the circuit. You

close the circuit again by merely pressing a button that restores the disk to its original position.

GROUND FAULTS

A normally grounded circuit may develop a ground on the ungrounded portion of the circuit. The resistance of this ground fault determines the extent of the trouble. A "heavily" grounded condition is equivalent to a short, and blows fuses. A "light" ground will not blow fuses, but will cause current leakage through the path of the ground.

Moisture is a common cause of grounds. Circuits exposed to weather must be carefully insulated, made watertight, against rain and salt spray. Yet material defects and reinstallations often destroy the watertight insulation, so here's another headache for you.

OTHER COMMON CAUSES OF CIRCUIT FAULTS

Shorts and grounds may also be brought about by—

EXCESSIVE HEAT--------- affects most insulating materials.

OIL AND GREASE--------- very soon cause deterioration of rubber insulation.

ACID AND PAINT--------- decompose many insulating materials.

MECHANICAL FACTORS--- kinks, sharp bends, friction (as when wires are pulled through a conduit) are invitations to gremlins.

CHAPTER 9

CELLS AND BATTERIES

ENERGY CHANGE

A battery is made up of cells. Each of them is a SOURCE of electrical energy. A cell or a battery does NOT store electricity in spite of the name, "storage battery." A battery supplies the electrical pressure needed to set electrons in motion throughout a circuit. You produce the electrical pressure by a chemical reaction which changes chemical energy into electrical energy.

CELLS

A cell is a complete voltage-creating unit. Every cell has two unlike plates known as ELECTRODES. They are separated from each other and immersed in a chemical solution called the ELECTROLYTE.

In a PRIMARY cell, one of the electrodes is chemically consumed to produce electrical current. Flashlight cells, the cells of "B" batteries, and

"dry" cells are examples of primary cells. In so-called "dry" cells, the chemicals are usually in the form of a paste instead of a liquid solution. The life of a primary cell is comparatively short, and depends on the amount of current drawn from the cell. Even when you are not using the cell, it deteriorates. When the cell is discharged, it cannot be recharged, and so must be discarded.

In a SECONDARY cell, the chemicals and electrodes are not irreversibly changed. The chemicals undergo reactions which are reversed by the recharging process. The lead-acid battery is made up of secondary cells.

You refer to the voltage of a cell as the CELL ELECTROMOTIVE FORCE (E_c). The voltage depends upon the chemical factors within the cell. The size of the cell has no effect upon the voltage.

The path of the current is through the electrodes and the electrolyte. These offer a definite resistance, the cell's INTERNAL RESISTANCE (R_i). The internal resistance varies with the size of the cell. In general, the larger the cell, the lower the internal resistance. The amount of current you can obtain from a cell is limited by the internal resistance.

CELL TERMINAL VOLTAGE

In (A) of figure 66, you have a 1.5-volt dry cell connected in a simple circuit. When the switch is open, the cell delivers no current, and the terminal voltage (E_t)—that is, the voltage across the terminals—will be the same as the cell voltage (E_c). The terminal voltage is also known as the OPEN-CIRCUIT or NO-LOAD VOLTAGE of the cells.

When you close the switch and a current flows, the terminal voltage decreases by an amount equal to the voltage drop across the internal resistance.

This voltage drop (IR), becomes greater as load circuit resistance is decreased to obtain higher current.

The fall in terminal voltage sets a definite limit to the amount of current you can draw in the circuit. If you reduce the load resistance to zero, as you see in (*B*) of figure 66, the cell is short-circuited and maximum current flows.

In the larger types of dry cells, the maximum current is approximately 30 amperes. The terminal voltage is zero in this case because the en-

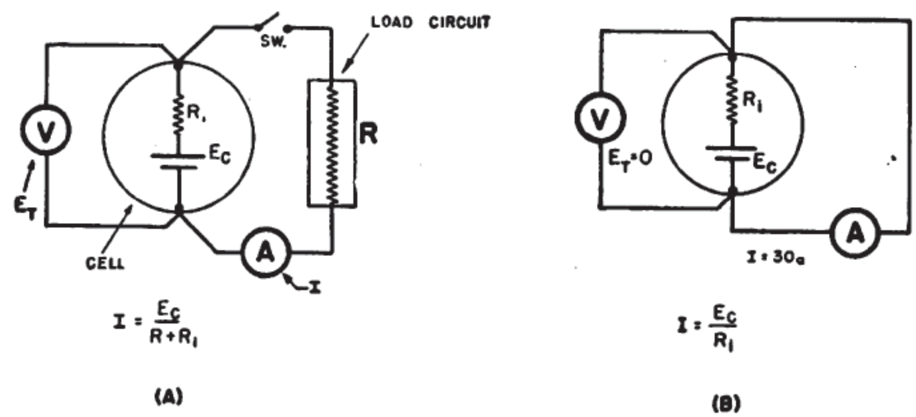


Figure 66.—Cell terminal voltage.

tire voltage is used to force current through the internal resistance of the cell.

Dry cells, as you see in figure 67, can be tested by short-circuiting the cell with an ammeter of sufficient range. This is one of the rare instances when you place an ammeter across a voltage source. Do not try this stunt with a storage cell unless you feel berserk and want to smash the meter.

In practical use, a cell is never required to deliver the maximum current obtained in short circuit. No energy is delivered to the load when the cell is short-circuited. The energy is all converted into heat within the cell itself, and in the conductor used to make the short circuit.

The strength of the current in a battery-operated circuit is limited by the effect of internal resistance on the terminal voltage. When high current is required, you must use some arrange-

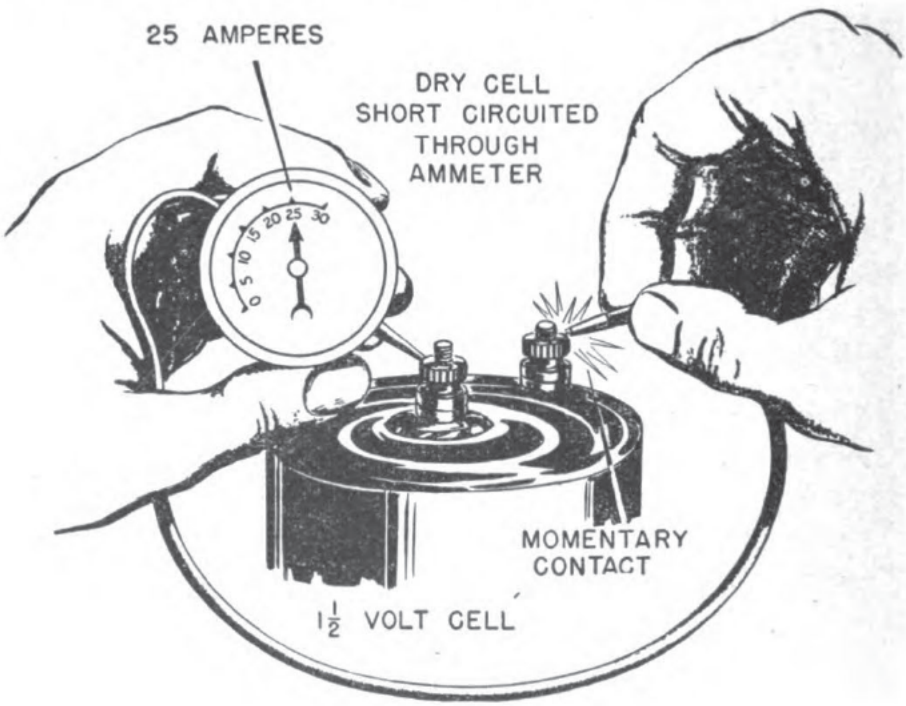


Figure 67.—Dry cell test.

ment that will lower the internal resistance of the voltage source.

In the discussion which follows, MAXIMUM CURRENT means current which the cell delivers with a moderate decrease in its terminal voltage.

CELLS IN SERIES

The voltage from a single cell is rarely sufficient for practical purposes. But you can connect a number of cells together IN SERIES to obtain any desired voltage.

To build up the series connection, connect the positive terminal of one cell to the negative terminal of the next cell. Then connect the positive

terminal of that cell to the negative terminal of the third cell, and so on.

The voltages of the combined cells act in the same direction to provide a total voltage equal to the sum of the individual cell voltages. From four 1.5 volt dry cells in series, you get 6 volts.

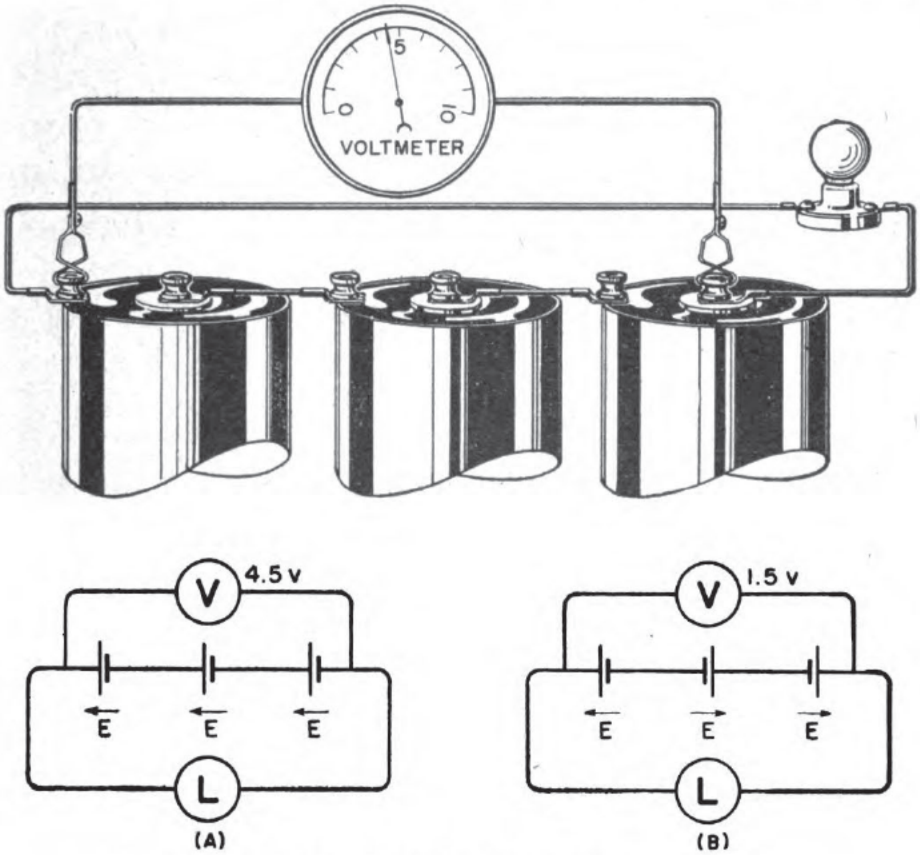


Figure 68.—Cells in series.

From three 2-volt cells in series, again you get 6 volts.

In (*A*) of figure 68, you have three dry cells in series. In (*B*) of figure 68, you see what happens when you connect them the wrong way.

The current in a circuit operated by cells in series depends upon TOTAL VOLTAGE, and TOTAL RESISTANCE. Be careful to get the point that the internal resistances of all the cells are IN SERIES with each other, and, besides, are IN SERIES with

the load circuit resistance. The following formula shows how the current depends on these resistances and the total voltage.

$$I = \frac{nE_c}{R + nR_i}$$

E_c = Cell emf.
R_i = Cells internal resistance.
n = Number of cells in series.
R = Load resistance
I = Load current.

FOR INSTANCE—

You have in series four dry cells, each with an emf of 1.5 volts and an internal resistance of 0.05 ohm. The cells are in a circuit whose resistance is 3.8 ohms. Find the current in the circuit.

$$I = \frac{nE_c}{R + nR_i} = \frac{(4)\ (1.5)}{3.8 + 4(0.05)} = \frac{6}{3.8 + .20} = \frac{6}{4} = 1.5 \text{ a.}$$

SOMETHING IMPORTANT TO UNDERSTAND

In previous problems involving Ohm's Law, you found out that an increase in voltage produces a proportionate increase in current. BUT THIS IS TRUE ONLY WHEN the resistance of the circuit is NOT INCREASED. In most cases, the resistance of the circuit is unchanged, or constant, because the load resistance is usually the major part of the total resistance and the internal resistance of the cells is NEGLIGIBLE. So any increase in voltage built up by the addition of more cells does not significantly increase the total circuit resistance.

When high currents are required, the load resistance is low and the internal resistance of the cells is just about as important as load resistance. Now, when you increase the voltage by adding more cells, you SIGNIFICANTLY increase the total resistance. You do NOT increase the current significantly. Hence, the MAXIMUM CURRENT you ob-

tain from a NUMBER of cells IN SERIES is NO HIGHER THAN the MAXIMUM CURRENT you obtain FROM A SINGLE CELL. Here you do not find any contradiction to Ohm's Law. The point is: The internal resistance of cells is a SIGNIFICANT factor whenever you have HIGH currents. You can get a clearer understanding of this point by comparing the result of shortcircuiting one cell and the result of shortcircuiting three cells.

FIRST, shortcircuit a 1.5-volt dry cell with an internal resistance of 0.05 ohm. What is the current flow?

$$I = \frac{nE_c}{R = nR_i} \qquad \begin{aligned} n &= 1 \\ E &= 1.5 \text{ volts} \\ R &= 0 \\ R_i &= 0.05 \text{ ohm} \end{aligned}$$

$$I = \frac{(1)\ (1.5)}{0 + (1)\ (0.05)} = \frac{1.5}{0.05} = 30 \text{ amperes}$$

NEXT, connect in series three dry cells, each with a voltage of 1.5 volts and an internal resistance of 0.05 ohm. Then shortcircuit the combination. What is the current flow?

$$I = \frac{nE_c}{R + nR_i} \qquad \begin{aligned} E &= 1.5 \text{ volts} \\ n &= 3 \\ R_i &= 0.05 \text{ ohm} \\ R &= 0 \end{aligned}$$

$$I = \frac{(3)\ (1.5)}{0 + 3(0.05)} = \frac{4.5}{0.15} = 30 \text{ amperes}$$

If you study these two examples, you can see why it is true the maximum current from a group of cells IN SERIES is no greater than that of a single cell. A threefold increase in voltage produces no increase in current because the total resistance—cell internal resistance, in this case—also is increased threefold.

REMEMBER—

You connect cells in series to build up REQUIRED VOLTAGES. But you do NOT thus build up the current.

CELLS IN PARALLEL

To build up a parallel combination of cells, you connect all the positive terminals to one conductor

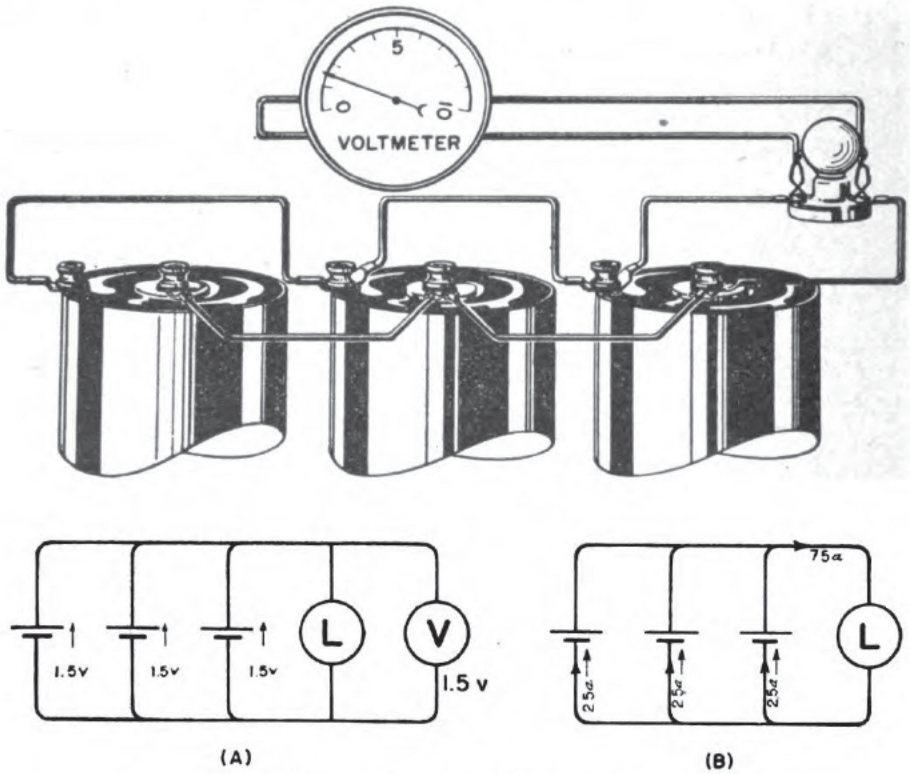


Figure 69.—Cells in parallel.

and all the negative terminals to another conductor. In (*A*) of figure 69, you have three 1.5-volt cells in parallel.

The total voltage of cells IN PARALLEL is the SAME as the voltage of a SINGLE cell. The total voltage of three 1.5-volt cells in parallel is 1.5 volts. TEN 1.5-volt cells in like combination is the same 1.5 volts. Obviously, you do not connect cells in parallel to build up voltage.

Why, then, connect cells in parallel? To build up amperage, of course. The TOTAL CURRENT you obtain from cells IN PARALLEL is equal to the SUM of the MAXIMUM CURRENTS you draw from the individual cells.

If each cell in (B) of figure 69 is rated at 30 amperes maximum, you obtain a total current of 90 amperes. If the load circuit requires 75 amperes, each cell supplies 25 amperes.

Cells in parallel must have the same electrical characteristics. Later, you will find out why.

Just as in the case of the series grouping of cells, the current in a circuit which operates by parallel cell combinations depends upon the total voltage and the total resistance. BUT the INTERNAL resistance of a parallel cell combination is equal to the internal resistance of one cell divided by the number of cells in parallel.

$$I=\frac{E_c}{R+\frac{R_i}{n}}$$

E_c = Cell emf (single cell).
R_i = Cell's internal resistance.
n = Number of cells in parallel.
R = Load resistance.
I = Load current.

FOR INSTANCE—

You have in parallel four cells, each with an emf of 1.5 volts and an internal resistance of 0.08 ohm. You connect this combination of cells to a lead circuit with a resistance of 0.28 ohm. What is the current in the circuit?

$$I=\frac{E_c}{R+\frac{R_i}{n}}=\frac{1.5}{0.28+\frac{0.08}{4}}=\frac{1.5}{0.28+0.02}=5 \text{ amperes}$$

A QUICK WAY TO WRECK CELLS

If you try to connect cells in parallel but don't quite succeed, you may have the result you see in (*A*) of figure 70. The voltage of both cells acts

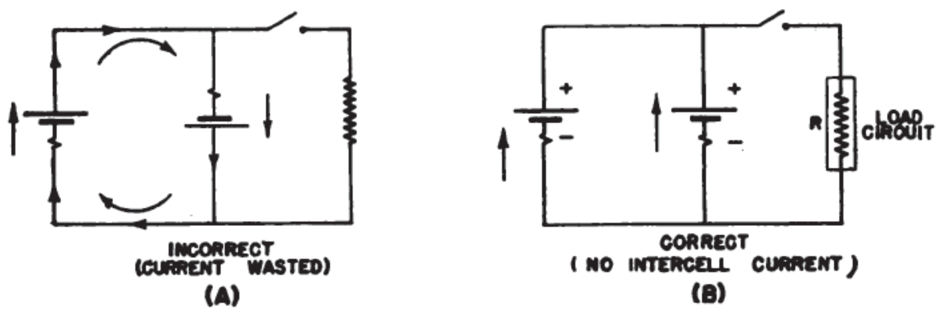


Figure 70.—Electrical polarity of parallel cell combinations.

in the same direction to send a high current through the complete circuit formed by the two cells. You have the equivalent of a short circuit

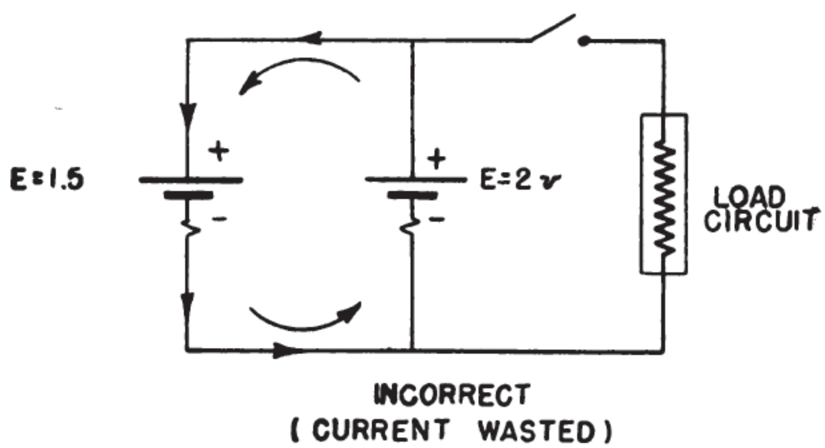


Figure 71.—Effects of unequal cell voltages.

in both cells, and quickly wreck both of them. In (*B*) of figure 70, you have the right connection.

EFFECTS OF UNEQUAL CELL VOLTAGES IN PARALLEL

Only cells of equal voltage should be connected in parallel. If you make a parallel connection of cells having different voltages, you get the

result you see in figure 71. The cell with the higher voltage discharges into the cell with lower voltage. Before long, both cells have the same lower voltage.

CELLS IN SERIES-PARALLEL

You want to supply a load circuit with 60 amperes at 6 volts, and you have 1.5-volt cells available.

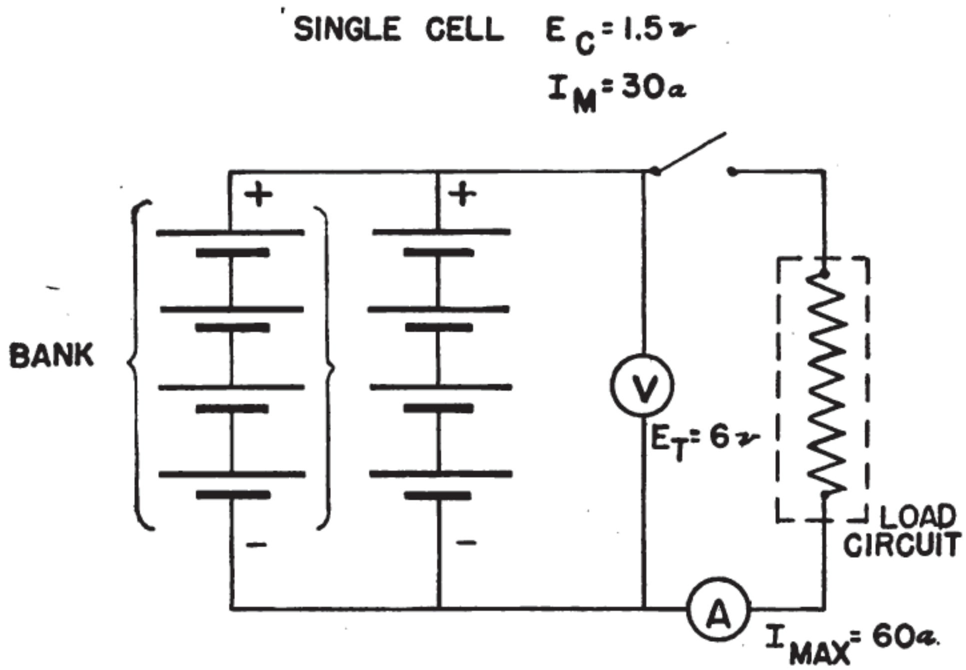


Figure 72.—Series-parallel cell combination.

able. The maximum current capacity of each cell is 30 amperes.

Four cells in series would give you the 6 volts. But from this bank of cells you can obtain only 30 amperes. What to do? Just make a second bank of four cells in series. Connect the two banks together IN PARALLEL, so you have a series-parallel combination. Thus, you have 60 amperes, each bank providing 30 amperes. However, the voltage of the two-parallel-connected banks is the same as the voltage of one bank. Note the scheme in figure 72.

Use a SERIES-PARALLEL arrangement of cells when you need more voltage in the load than the maximum voltage of a single cell, AND ALSO, when you need more current in the load circuit than the maximum current of a single cell.

You already know that only cells of equal voltage should be placed in parallel. Similarly, a bank of cells in series should be placed in parallel only with a bank having the same total voltage. Place banks of unequal voltage in parallel and

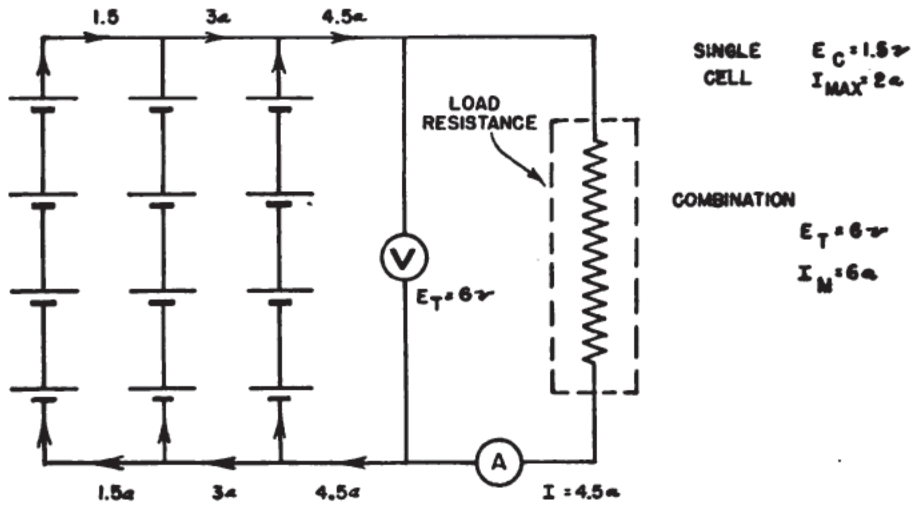


Figure 73.—Cells in series-parallel—problem 1.

what happens? A waste current circulates in the circuit formed by the two banks. Before long, the bank with the higher voltage discharges to the point where its terminal voltage equals that of the other bank.

Use the following problems to test your understanding of series-parallel set-ups.

> An ignition coil requires 4.5 amperes at 6 volts. How many flashlight cells will be required to supply this coil, if each cell has a potential of 1.5 volts and a maximum current capacity of 2 amperes? Diagram.

The answers are in figure 73.

Note that two 4-cell banks yield 4 amperes—INSUFFICIENT. Three 4-cell banks supply 6 amperes—MAXIMUM.

A starter motor requires 285 amperes at 12 volts. How many cells are needed, if

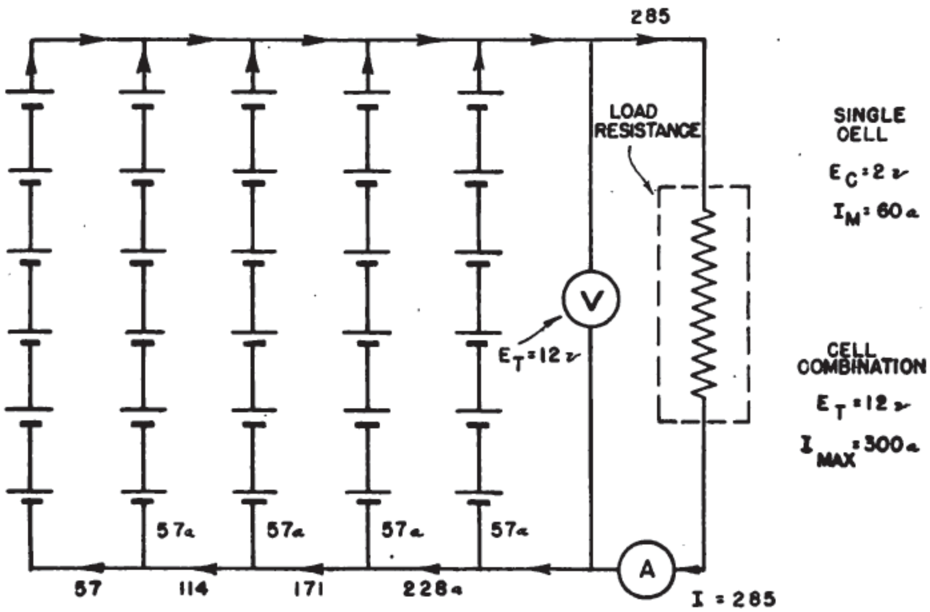


Figure 74.—Cells in series-parallel—problem 2.

each cell is rated at 2.0 volts and a maximum current of 60 amperes? Diagram. The answers are in figure 74.

"BUTTON UP" ON CELLS IN SERIES, PARALLEL, AND SERIES-PARALLEL

Cells in	Why?	Total voltage	Maximum current	Total internal resistance
Series	To build up voltage.	Sum of cell voltages.	That of single cell.	Sum of cell's internal resistance.
Parallel	To build up current.	That of single cell.	Sum of cell amperages.	Single cell's internal resistance divided by number of cells.
Series-parallel	To build up both current and voltage.	Sum of voltages of cells in one bank.	Sum of bank amperages.	Total internal resistance of one series bank divided by number of banks in parallel.

In airplanes, the storage battery is an indispensable source of electrical energy. In conjunction with a motor-driven generator, the battery supplies energy to operate the engine starter, lighting system, radio and other electrical equipment.

In figure 75, you have a battery made up of three lead-acid type cells in series. Each cell has positive plates connected at the top to form the positive electrode of the cell, and a set of connected negative plates to form the negative electrode. There is one more negative plate than there are positive plates. The positive plates are coated with LEAD PEROXIDE and have a chocolate-brown color. The negative plates are coated with SPONGE LEAD and have a pearl-grey color. The plates are separated by sheets of porous wood or hard rubber. These sheets are called SEPARATORS. The electrolyte is sulfuric acid diluted with distilled water.

When the storage battery is discharging, both sets of plates become coated with lead sulfate, and the concentration of the acid is reduced. As soon as both sets of plates are thoroughly coated with lead sulfate, the storage battery is "dead." But it can be recharged by means of a direct current which restores plates and electrolyte to their original condition.

STATE OF CHARGE

A storage battery may be fully charged, half charged, normally discharged, or completely discharged (DEAD).

A NORMALLY DISCHARGED battery is at the point where it should be recharged. But you CAN still use the battery for a short time at LIGHT load.

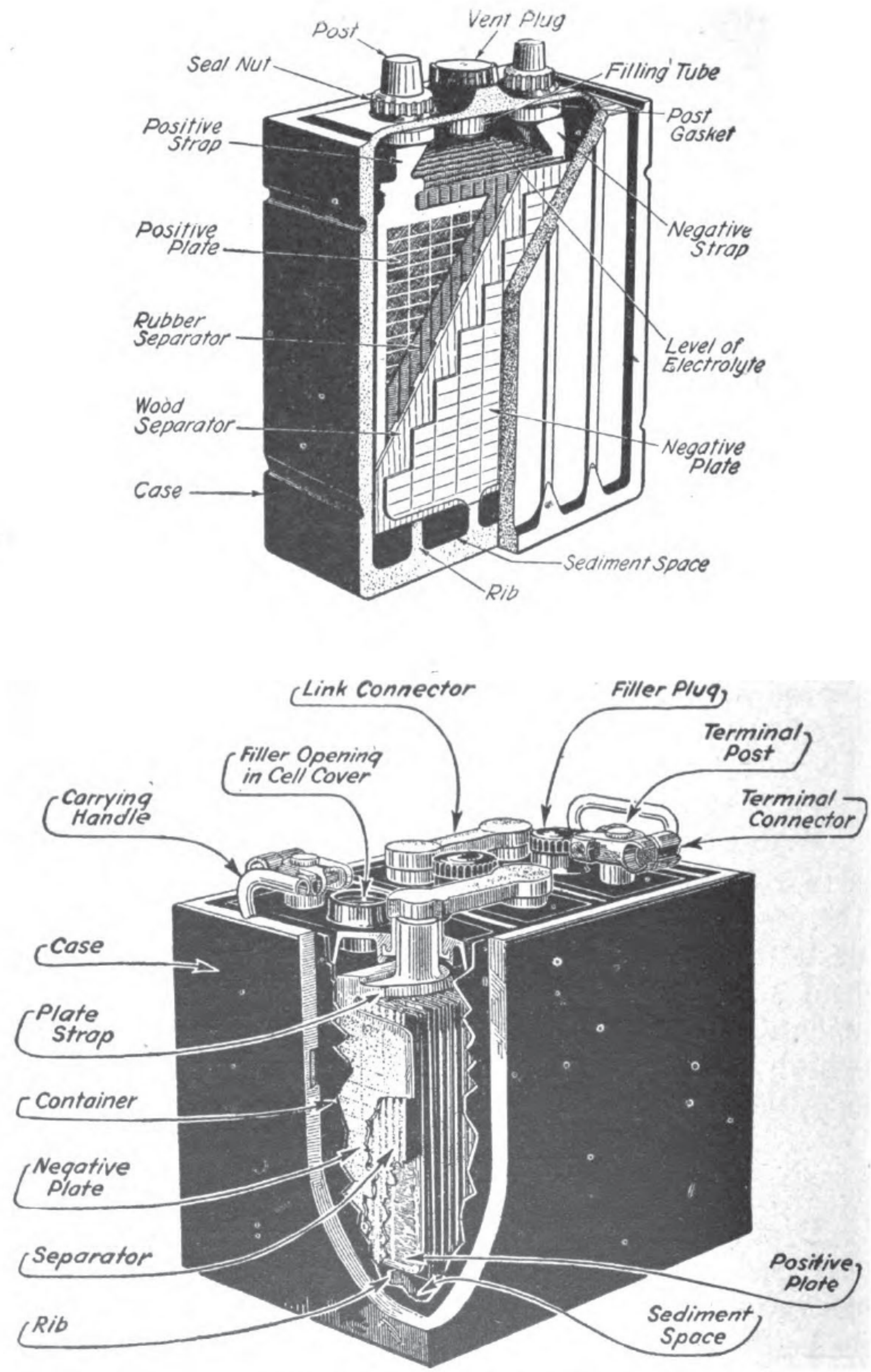


Figure 75.—Storage battery.

Continued use past this point ends in complete discharge. Then you have a DEAD battery on your hands. You can recharge the dead battery. However, a satisfactory recharging takes more time than when the battery is only normally discharged.

ELECTRICAL CHARACTERISTICS OF STORAGE BATTERIES

The voltage of any lead-acid CELL is approximately 2 volts. The size of the cell has no effect on the voltage. A small cell has the same voltage as a large cell. Usually, an airplane storage BATTERY is made up of 6 cells, and, usually, you

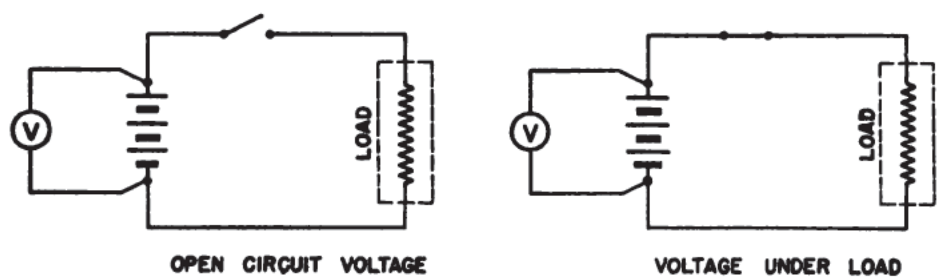


Figure 76.—Measuring battery voltage.

can obtain a potential of 12 volts at the battery terminals.

Make a voltage measurement when a battery is not connected to a load circuit, and you get the open-circuit voltage, or NO-LOAD VOLTAGE. See figure 76. If your measurement is made when a battery is connected to a heavy load, such as a starter motor, the voltage measured at the terminals of the battery is considerably less than the no-load voltage. When you place the battery on CHARGE, the voltage is slightly higher than the no-load voltage.

The current that is delivered by a battery depends on the resistance of the load circuit. As you would guess, the lower the load resistance

the higher the current. On short circuit, a battery delivers maximum current. Although the size of the battery cells and the number of plates per cell have no effect on the voltage, the internal resistance and the amount of current do depend on the size and construction of the battery cells. The current also depends on the state of charge of the battery.

AIRPLANE STORAGE BATTERIES

Storage batteries for airplanes must be compact and light, yet very rugged. They must be shielded to prevent radio interference, and cell-ventilating plugs must be so constructed that the electrolyte will not escape from the battery when you are heels-over-head. The plates and separators are thin. The electrolyte has a full-charge specific gravity of 1.285 corrected to 77° F.

A specially constructed vent plug with an automatic valve is installed in each cell for escape of gases released within the cell. When the battery is tilted to an angle of 45°, these valves automatically close and so prevent leakage if there is more tilting. ADDING TOO MUCH WATER WILL CAUSE FLOODING IN SPITE OF THE VENT CONSTRUCTION.

An aluminum casing shields against radio interference and makes the assembly more rugged. This casing has a cover with holes for ventilation. The joints between cover and casing are well sealed with a special gasket. A set of battery hold-down rods is fitted through slots in the cover and holds the entire assembly rigidly in place. For making rapid electrical connections, a terminal outlet box with removable cover is provided at the side of the aluminum container.

To save time in recharging, you should recharge a battery BEFORE it becomes completely discharged. To find out when recharging is necessary, you must test the state of charge.

Why not simply measure the open circuit voltage? Your voltmeter across the terminals indicates 2 volts—when the battery is normally discharged, when it is half charged, when it is fully charged. Only when the battery is dead, or its plates badly shorted, does your voltmeter across the terminals indicate less than 2 volts.

SPECIFIC GRAVITY MEASUREMENT

By measuring the SPECIFIC GRAVITY (S. G.) of the electrolyte, you can determine with considerable accuracy the state of charge of a battery.

Specific gravity is the ratio of the weight of a substance to the weight of an equal volume of water.

$$\text{Specific gravity} = \frac{\text{Weight of any volume of a substance}}{\text{Weight of the SAME volume of water}}$$

Suppose that you have a liquid, a gallon of which weighs 20 pounds. The weight of a gallon of water is 8 pounds. The specific gravity of the liquid is $20 \div 8$, or 2.5.

The electrolyte of a lead-acid storage cell is a solution of sulfuric acid in water. The S. G. of the electrolyte depends upon the concentration of acid in the water. Because sulfuric acid is a heavy liquid, the more sulfuric acid present the greater the S. G. of a sulfuric acid solution.

The S. G. of a fully charged battery varies between 1.270 and 1.300. As the battery dis-

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charges, the acid combines with material on the plates, and therefore the S. G. gradually drops. When the battery is normally discharged, the S. G. has fallen to 1.150. When you are charging the battery, the acid is gradually restored to the electrolyte, and therefore the S. G. rises.

The readings just given are usually referred to as—

1.150	eleven-fifty
1.270	twelve-seventy
1.300	thirteen-hundred

BATTERY HYDROMETER

To measure quickly the S. G. of a storage battery, you use a HYDROMETER, such as you see in figure 77. You draw a sample of the electrolyte into the glass tube, which contains a small float loaded with shot at one end and a scale marked with specific gravities at the other end. The float takes a position that depends upon the S. G. of the electrolyte. The lower the S. G., the lower the float sinks in the electrolyte.

HOW TO USE A HYDROMETER

HERE'S HOW TO FIND OUT THE S. G. OF A BATTERY BY MEANS OF A HYDROMETER.

Remove the vent caps from the cells.

Squeeze the hydrometer bulb, and then insert the end of the rubber tube into the cell and below the surface of the electrolyte. Hold the hydrometer by the glass neck.

Slowly release the rubber bulb, to draw the solution into the glass chamber until the float floats free. You should completely release the bulb. If you draw too much of the electrolyte into the hydrometer, expel the acid by squeezing the bulb, again insert the end of the rubber tube into the electrolyte, and then release the pressure

Figure 77.—Battery hydrometer.

on the bulb. Repeat these operations until you have the right amount of liquid in the glass chamber.

If and when the upper end of the float sticks to the side of the glass tube, tap the glass gently to free the float.

Note the reading on the float stem—precisely at the surface of the liquid.

The reading at this level is the S. G. of the electrolyte.

Expel the electrolyte to the cell. Be careful not to spill the acid.

Read the S. G. of each cell.

S. G. TEMPERATURE CORRECTION

If the temperature of the battery is several degrees above or below 77° F., you must correct the hydrometer reading for temperature. To your reading, add 0.001 for every 3° that the battery temperature is above 77° F. Subtract 0.001 for every 3° that the battery temperature is below 77° F. In common practice, the decimals are dropped from the S. G. reading. So you would add or subtract 1 instead of 0.001 for every 3° above or below 77° F.

In figure 78, you have a chart to show corrections. In using the chart, you find the temperature in the left column and note the number opposite in the right column. If the number is +, add it to the S. G. reading. If the number is −, subtract it from the S. G. reading.

FOR INSTANCE—

> If, at 35° F., the S. G. reading is 1280, then $1280-20=1260$.
>
> If, at 95° F., the S. G. reading is 1210, then $1210+8=1218$.

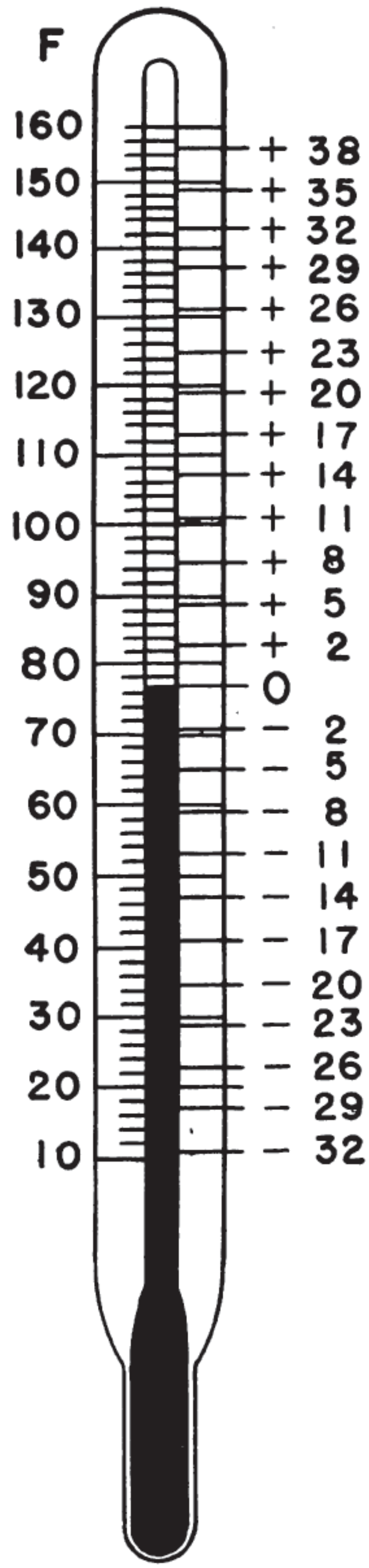


Figure 78.—Specific gravity temperature correction.

HIGH-AMPERAGE DISCHARGE TEST

The high-amperage discharge test is the most accurate and informative test you can use to determine battery condition. In this test, you place across the terminals of the CELL a low-resistance

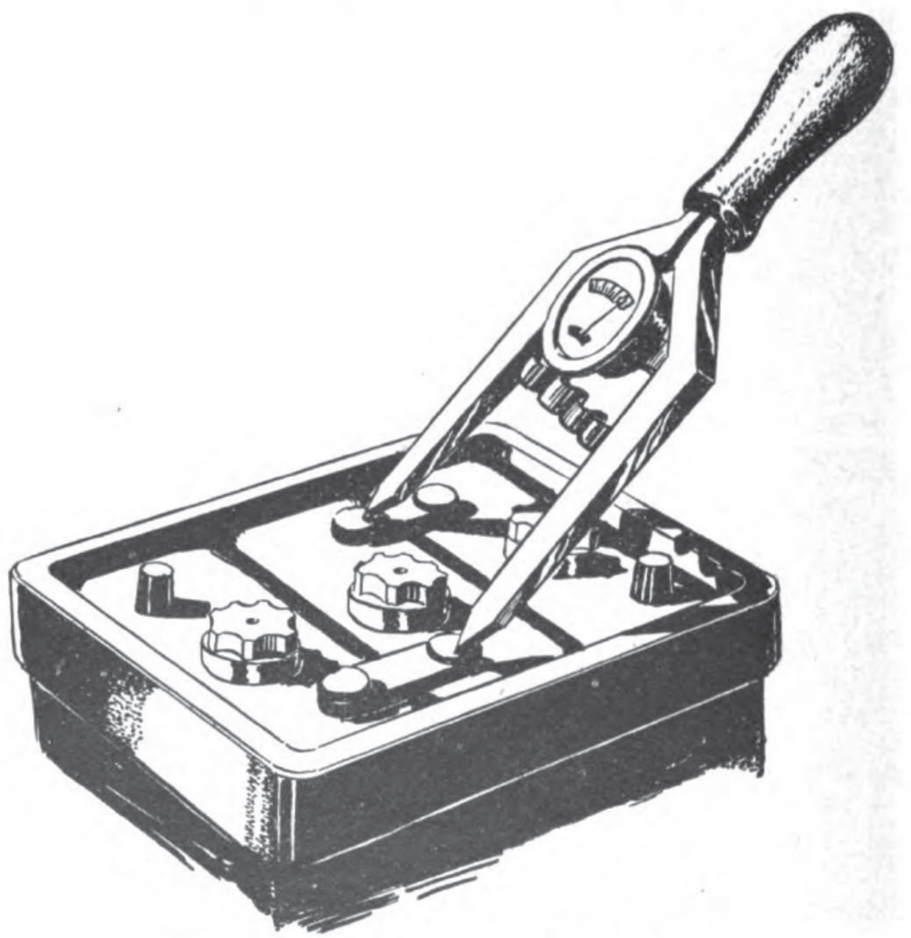


Figure 79.—High amperage discharge tester.

load in series with a high-range ammeter that measures the discharge current.

The ability of the cell to maintain this current for a definite period of time is a satisfactory indication of the ability of the cell to function in actual operation. The test is chiefly of value in comparing cells with each other in regard to performance.

In figure 79, you have a Weston high-amperage cell tester. It is essentially an ammeter with a metallic strip across the prongs acting as both load circuit and ammeter shunt. The prongs are just far enough apart to serve as a bridge across the terminals of any standard type of battery cell. For a complete test, you must check every cell of the battery.

Other factors besides the state of charge cause the discharge reading to vary. Over a given period a small battery will not give the same current value as a larger unit having a lower internal resistance. Too short a period for a reading makes the test inconclusive. Too long a period involves excessive discharge that serves no purpose. A discharge of 300 amperes for a period of 10 to 30 seconds is a satisfactory discharge reading for the average battery. From manufacturer's specifications, or from a similar battery in good condition, you can obtain the standard readings for any make of battery.

The scale on a high-amperage cell tester is usually calibrated in volts. You will find that the voltage at the terminals of a storage battery drops to a lower value as soon as current flows. The drop is proportional to the current. The lights on a car dim perceptibly when you step on the starter. The high current drawn by the starter causes an appreciable drop in battery voltage. Voltage drop is greater if the battery is nearly discharged. So, by observing the voltage drop under load, you can gage the state of charge.

If a cell is in good condition, the terminal voltage will remain above 1.75 volts. A greater drop within the period of 10 to 30 seconds usually indicates a discharged cell. If the cell is charged and still shows a voltage drop below 1.75 volts, you have a faulty cell.

AMPERE-HOURS

The electrical capacity of a storage battery is rated in AMPERE-HOURS. If you have a fully charged battery that is rated at 100 ampere-hours, you can expect it to last 100 hours on a load circuit requiring current at the rate of 1 ampere. Or you can expect it to discharge for 50 hours at the rate of 2 amperes. You might think such a battery should last for 1 hour at a discharge rate of 100 amperes. BUT actually you couldn't maintain such a high current.

THE AMPERE-HOURS RATING IS AN INDICATION OF THE LENGTH OF TIME A BATTERY MAY DISCHARGE AT A GIVEN RATE.

BATTERY CHARGING

As soon as the S. G. of a storage battery drops to 1.150 ("eleven-fifty"), you want to get busy and charge it again.

If a battery becomes completely discharged, you better work fast. Sulfation results when you let it stand. Sulfation is the hardening of the lead sulfate which formed on both positive and negative plates. It reduces the effective plate area and the ampere-hour capacity of the battery. Unless you remove the lead sulfate immediately, the ampere-hour capacity is permanently reduced.

The charging rate is the AMPERAGE, or strength, of the charging current. The maximum charging rate depends upon the condition of the battery. For a completely discharged battery or a normally discharged battery, you may use a very high charging rate. 50 to 200 amperes are alright, if you have to bring up the charge in a short period of time. BUT, with such high charging rates, you MUST keep the temperature of the electrolyte be-

low 110° F. You MUST reduce the charging rate if the temperature rises above 110° F. The normal charging rate for airplane batteries is specified on the name plate of each battery.

The TIME required to charge a battery depends upon the state of charge and the charging rate. Always continue the charging until the battery is fully charged. How do you tell when the battery is fully charged? If three successive S. G. readings made at half-hour intervals are the same, the battery is fully charged.

BATTERY CURRENT—CHARGE AND DISCHARGE

In (*A*) of figure 80, note that when a battery discharges, current flows from the positive terminal and into the negative terminal. To charge, you must send a direct current through the battery in the opposite direction. You charge by connecting the battery to a CHARGER that provides voltage higher than that of the battery. As you see in (*B*) of figure 80, you connect the positive terminal of the generator to the positive terminal of the battery, and complete the circuit by connecting the negative terminals. If the genera-

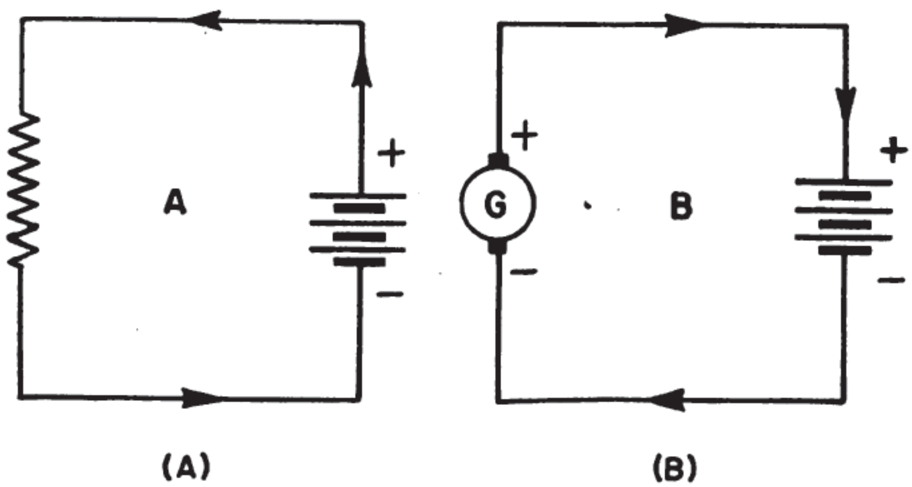


Figure 80.—Battery current—charge and discharge.

tor voltage were lower than the battery voltage, the battery would discharge by sending current through the generator. In charging circuits in airplanes and automobiles, such a reversal of current is prevented by use of a cut-out relay which disconnects the circuit when the generator voltage drops below a definite value.

In airplanes and automobiles, batteries are charged by the use of a generator driven by the engine. When 110-volt d. c. is available, you may charge batteries directly from this source by the use of suitable current-regulating devices. When a. c. is used, the current must be rectified—that is, changed to d. c.—before being run into the battery.

THE TUNGAR RECTIFIER

In figure 81, you have a diagram of a Tungar rectifier battery charger. The charger has a transformer with taps, a selector switch, and a rectifier bulb. To points *K* and *G*, two batteries are connected for charging. The charging current must flow through the batteries from *K* to *G*, a direction opposite to the current flow during battery discharge. Because the batteries are in series, the voltage across points *K* and *G* is 12 volts, and *K* is positive with respect to *G*. So when the switch is closed, current will flow from *K* to *G* only if a d. c. voltage greater than 12 is present across points *M* and *N*.

The voltage across the entire transformer *A* to *B*, is 110 volts a. c. The voltage across points *R* and *S* depends on the position of the selector switch and can be made anything between 10 to 110 volts. This voltage is also an alternating voltage. If you applied it to the points *K* and *G*, it would send current from *K* to *G* during one fraction of a second, and then from *G* to *K* dur-

ing the next fraction of a second. And so the action would continue back and forth, alternately charging and discharging the battery. But you eliminate the discharge part of the cycle by placing a Tungar bulb in the charging circuit. The bulb permits current to flow from the plate *P* to the filament *F*, but will not permit it to flow in the reverse direction. The current therefore passes in only one direction through the batteries.

You can charge from 1 to 15 batteries at the same time with the Tungar charging system. The

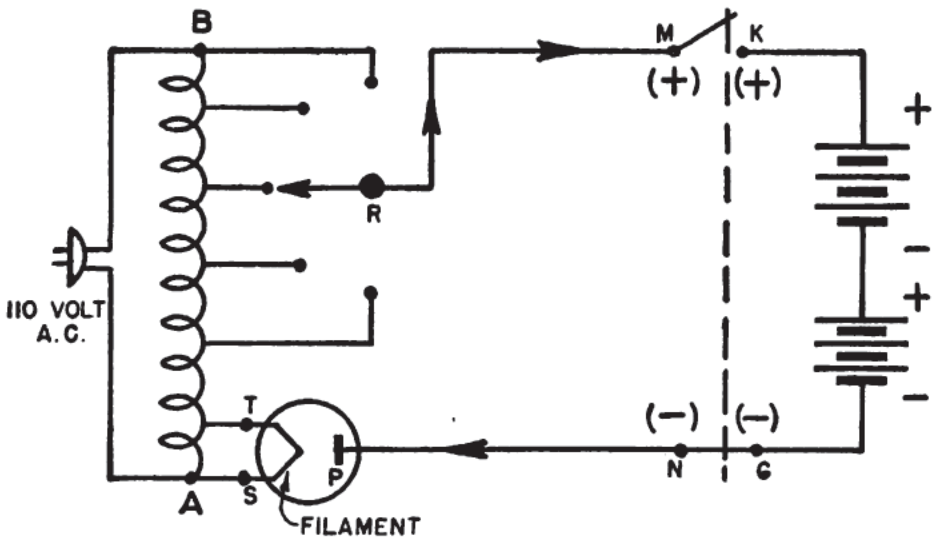


Figure 81.—The Tungar rectifier.

batteries are invariably connected IN SERIES, and so the current is the same through each battery.

CONSTANT POTENTIAL CHARGER

In figure 82, you see a diagram of a constant potential charger—a director pole d-c generator, driven by a constant-speed a-c motor. The voltage at the generator brushes is the same as the line voltage applied to the batteries, and can be set at any value within a certain range by regulating the resistance in the field circuit of the generator. Because the resistance of the genera-

tor armature, brushes, and line, or bus bar, are low, the generator voltage stays constant over a wide range of output current.

Batteries to be charged are connected directly across the charging line. You have a separate switch for each battery, so it is easy to connect or disconnect a battery. By placing the switch in an intermediate position (X), you can read the charging current to each particular battery.

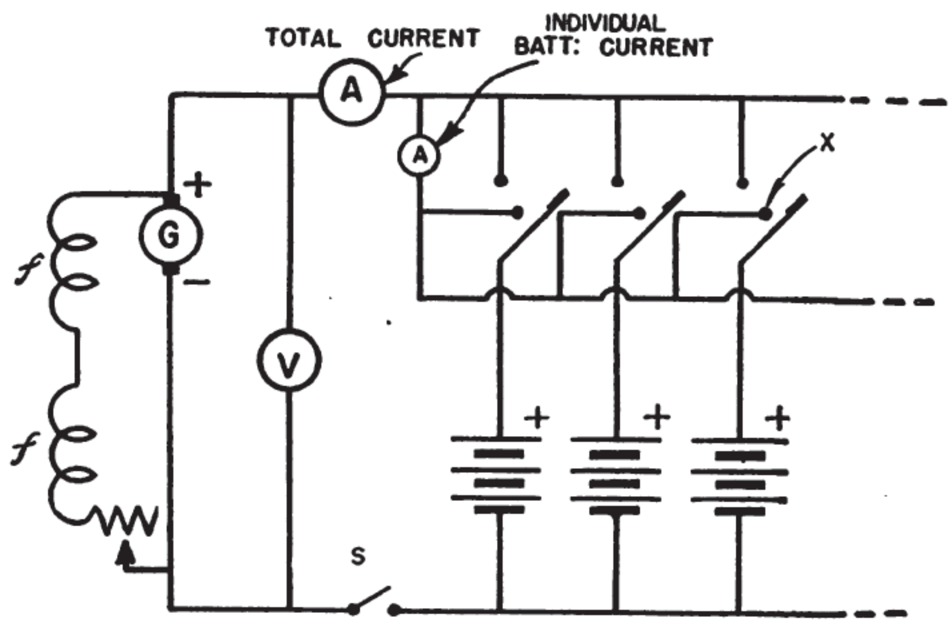


Figure 82.—The constant potential charger.

In this charging system, batteries on charge are all in parallel with each other. Hence they are independent of each other. The strength of the charging current depends on the resistance of the various parts of the circuit and the difference in voltage between battery and generator. The greater this difference, the higher is the charging rate.

Although the charger itself maintains constant voltage, the battery voltage does not remain the same during a charge but rises slightly as the cells become fully charged. The voltage difference

therefore decreases and the charging rate must decrease correspondingly. Here you have a TAPERING effect on the charging rate. On charge in this system, a battery receives current according to the need for it. When the battery is completely discharged, there is a large voltage difference, and the charging current is high. As the battery comes up to charge, the rate tapers off automatically, so that when fully charged, the battery receives very little current.

WHEN THE GENERATOR IS SHUT DOWN, THE SWITCH AT *S* MUST BE OPENED. If you do not open this switch, the batteries discharge as a group in parallel and turn the generator as a motor. Also individual battery switches must be opened as each battery becomes fully charged. Otherwise, fully charged batteries will discharge into those not completely charged.

MAINTENANCE OF STORAGE BATTERIES

The life of a storage battery depends on use, proper charging, duration of charge, and maintenance of the electrolyte level. Take good care of a battery, and it should last several years. Neglect it, and you may ruin it in a short time. Here are important rules for the satisfactory maintenance of a storage battery.

Test the battery at least ONCE EVERY WEEK.

If a battery is COMPLETELY discharged, RECHARGE it AT ONCE.

In CHARGING a battery, select a charging RATE CONSISTENT WITH THE TIME available for charging.

When time is available, use the normal rate indicated on the name plate.

If it is necessary to charge a battery at a very high rate, keep a careful check on the temperature and never let it exceed 110° F.

When cells gas freely, reduce the charging rate to the normal rate.

Never try to charge batteries to a definite specific gravity.

Maintain the charge until three successive S. G. readings at half hour intervals are the same.

By regular addition of distilled water ONLY, maintain the electrolyte 3/8 of an inch, or more, above the top of the separators—according to manufacturer's specifications. Boiled water CANNOT be used. Rapid deterioration of a battery will result if you allow the electrolyte level to remain below the top of the separators.

Add distilled water immediately before recharging a battery. In the process of charging a battery, the water in the electrolye is decomposed into hydrogen gas and oxygen gas, which escape through the vent holes. You MUST restore this water, so that level of the electrolyte is maintained.

Never use a match when you check electrolyte level. Hydrogen and oxygen mixed together are highly explosive.

The room used for recharging must be well ventilated.

Never disconnect leads to a battery while it is on charge. The spark that occurs at the terminals may ignite the gas.

Do not atempt to take a S. G. reading just after you have added distilled water to a battery. Addition of distilled water dilutes the electrolyte and lowers the S. G. A reading then would indicate a state of charge below the actual condition of the battery.

Try to keep from spilling any electrolyte when testing a battery with a hydrometer.

Never add acid or electrolyte to a battery unless it has been definitely determined that some electrolyte has been lost. If it is ever necessary to prepare electrolyte, remember that acid must be added to water slowly.

When placing a battery on charge, do not remove the vent plugs. Thus you prevent acid spray from reaching the top surface of the battery.

Keep the terminals of a storage battery free of any deposits that may form on it so that the metal will not be eaten away. The presence of a greenish-white formation on battery terminals indicates corrosion. Remove such material by using a wire brush thoroughly on the affected parts. Then apply a strong solution of baking soda to all corroded points to neutralize any acid that remains. Wash the battery with fresh water and dry with compressed air or a cloth. Finally, coat the terminals with petrolatum or melted paraffin.

Do not draw heavy discharge current except for short intervals of time. If you need a high current for a long period, use batteries connected in parallel.

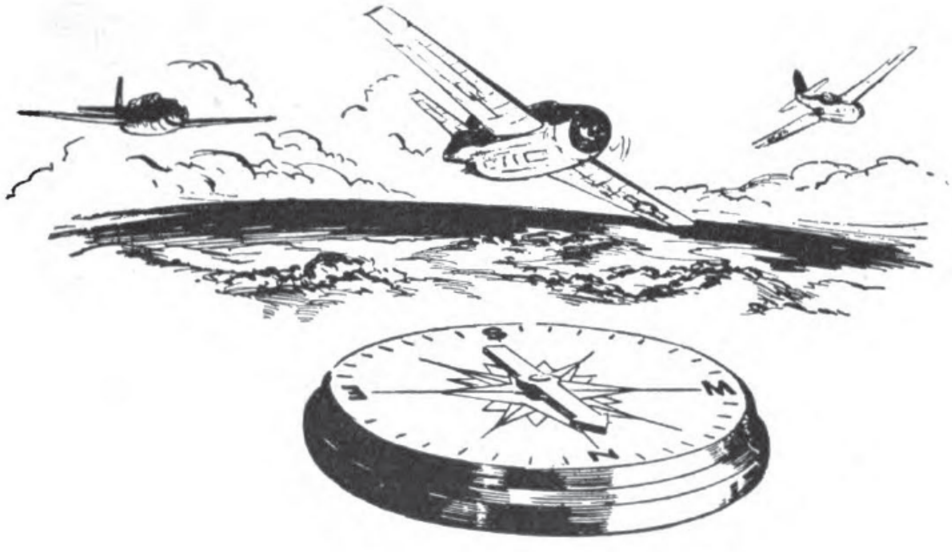
Never allow a battery to be mounted in a manner that will subject it to strong vibra-

tions. You don't want a cracked cell. Rough handling of batteries may also crack cells.

Never add "restorer" concoctions to a battery. These "patent medicines" are all worthless.

Test storage batteries more frequently in very cold weather than in warm weather. A discharged battery freezes easily.

FOLLOW THESE MAINTENANCE RULES AND THE BATTERIES UNDER YOUR CARE WILL GIVE A GOOD ACCOUNT OF THEMSELVES.



CHAPTER 10

MAGNETISM

MAGNETIC SUBSTANCES

Magnetism, is an invisible force. It cannot be sensed in any manner except through its effects upon certain materials, especially iron and its alloys, including steel.

The ancients discovered that an iron ore, magnetite, has the unique natural ability to attract iron. In figure 83, you see what happens when a piece of magnetite is touched to a pile of iron brads. They cling to this NATURAL MAGNET.

ARTIFICIAL MAGNETS can be made in several ways. You can stroke a steel knitting needle with a piece of magnetite, and thus magnetize the needle. You would have to stroke the needle in one direction only, and lift the magnetite free of the needle at the end of each stroke, to bring the natural magnet back to the opposite end of the needle for the beginning of the next stroke.

You could readily prove that the needle has been magnetized. Dip an end into iron filings.

The filings cling to this end like so much black fuzz. If you sprinkle iron filings on a piece of paper and lay the magnetized needle in their

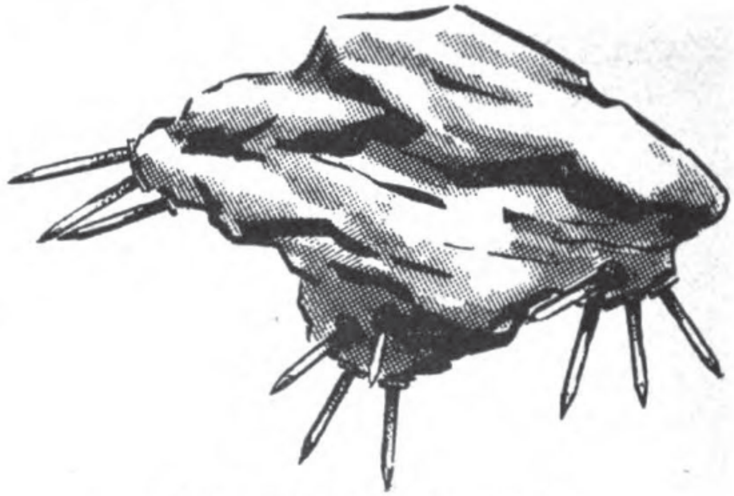
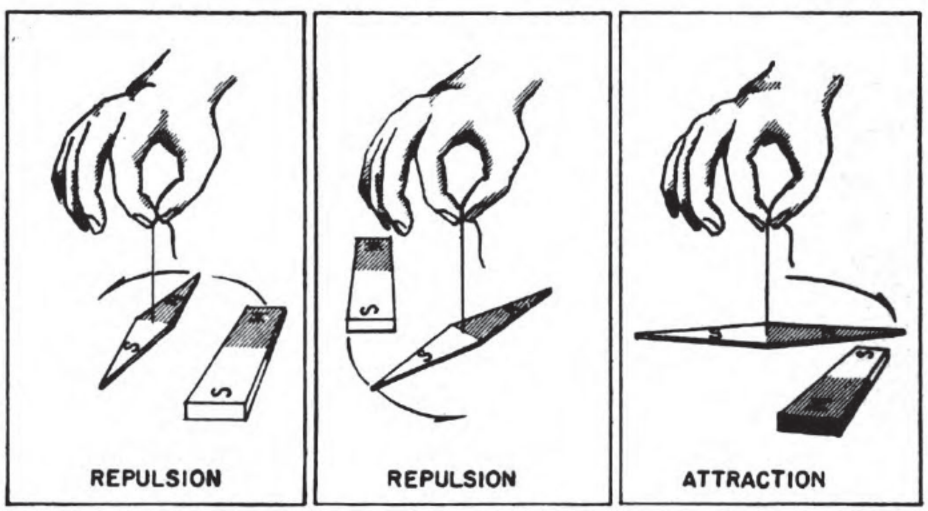


Figure 83.—Natural magnet.

midst, a tuft of filings will cling to each end. But only a few scattered filings will be held elsewhere on the needle. Hence, there are two centers of



Figue 84.—Like poles repel, unlike poles attract each other.

attraction—that is, two POLES. Every magnet has at least two poles. It is possible for a magnet to have more than two poles.

Suspend a magnetized needle so that it is free to move horizontally. You will find the needle comes to rest in a north and south direction. A

compass needle is just such a magnetized piece of steel. Note that one pole ALWAYS is attracted by and points in the general direction of the north pole of the earth. This pole is called the NORTH pole of the magnet. The other end is the SOUTH pole.

As you can see from figure 84, like magnetic poles REPEL each other. Unlike magnetic poles ATTRACT each other.

MAGNETIC FIELD

You have noted that magnets can influence one another at a distance without actually coming

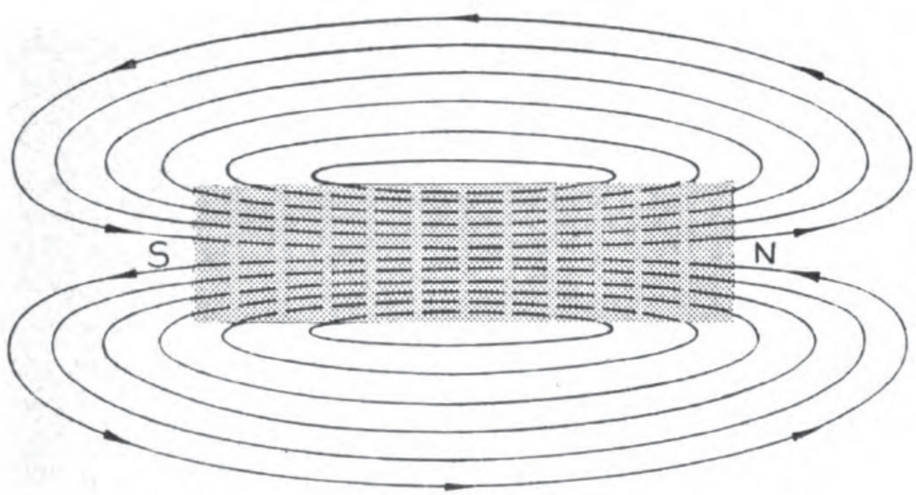


Figure 85.—Flux pattern—bar magnet.

into contact. The space through which this invisible force acts is known as a MAGNETIC FIELD. The force itself may be represented by MAGNETIC LINES OF FORCE, often collectively termed MAGNETIC FLUX. In common electrical lingo, the three terms, magnetic field, lines of force, and magnetic flux, mean the same thing and are used interchangeably.

To demonstrate a magnetic field more clearly than by simple attraction or repulsion of poles, sprinkle iron filings on a piece of cardboard placed atop a bar magnet. You obtain the pattern in

figure 85. With a horseshoe magnet, you obtain the pattern in figure 86. The patterns assumed by the filings indicate the magnetic lines of force, or magnetic flux. BUT, because of the limitations

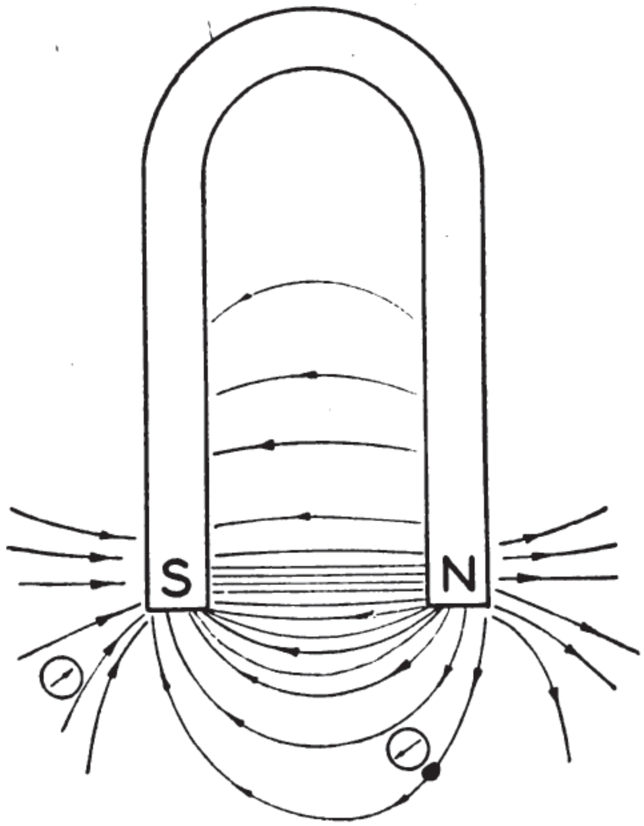


Figure 86.—Flux pattern—horseshoe magnet.

of your method, only the horizontal lines are indicated. The lines of force actually SURROUND the poles.

The number or concentration of lines indicates roughly the magnetic strength at various points around the magnets. The magnetic force is greatest near the poles, and the field is weaker elsewhere.

The pattern of the field about two unlike poles is shown in figure 87, and that about like poles, in figure 88. Note that there are three distinct loops in the case of attraction and four loops in the case of repulsion.

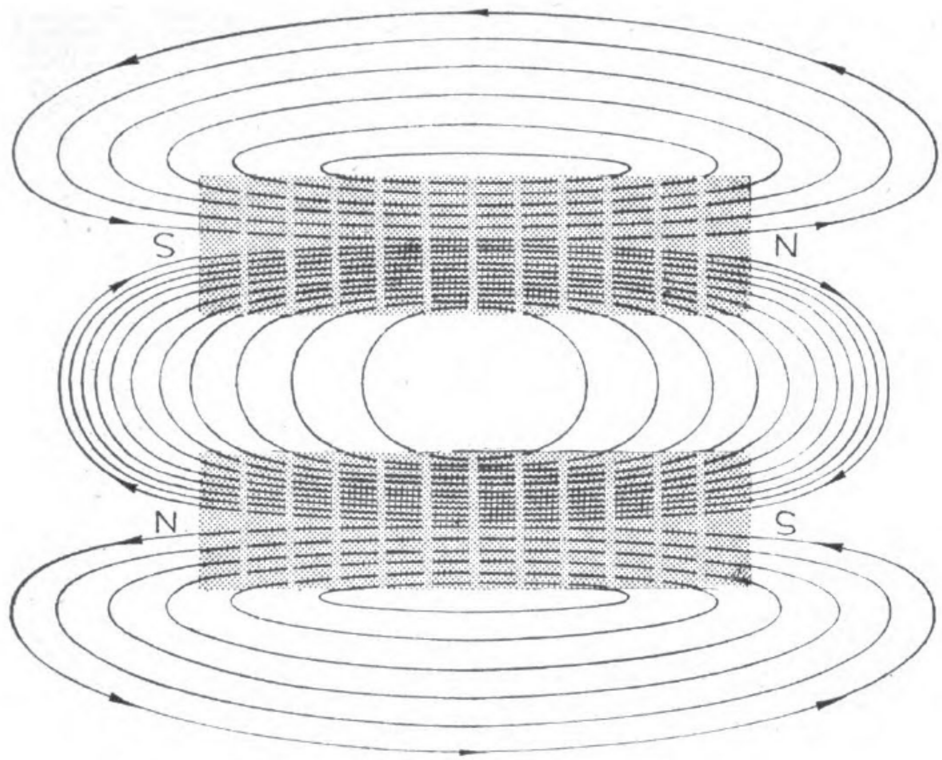


Figure 87.—Flux pattern—attraction.

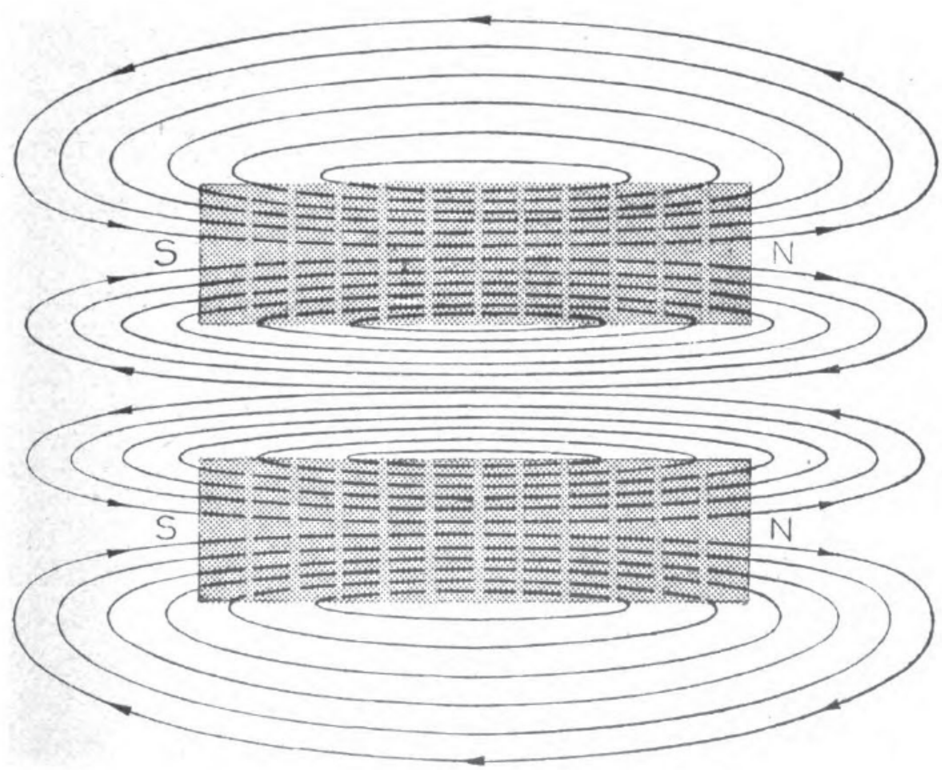


Figure 88.—Flux pattern—repulsion.

CHARACTERISTICS OF LINES OF FORCE

Lines of force are closed loops passing through the magnet and the space around it.

These loops, like stretched rubber bands, tend to shorten lengthwise.

Lines of forces do not cross each other.

The number of lines of force concentrated at a point is an indication of magnetic strength at that point.

Lines of force have direction. They emerge from the north pole and enter the south pole. To demonstrate this characteristic, place a compass in a magnetic field, and note that, wherever you place the needle, its north pole indicates the direction of the lines of force.

MAGNETIC COMPASS

If you don't know what a magnetic compass is, now is the time to find out. The magnetic com-

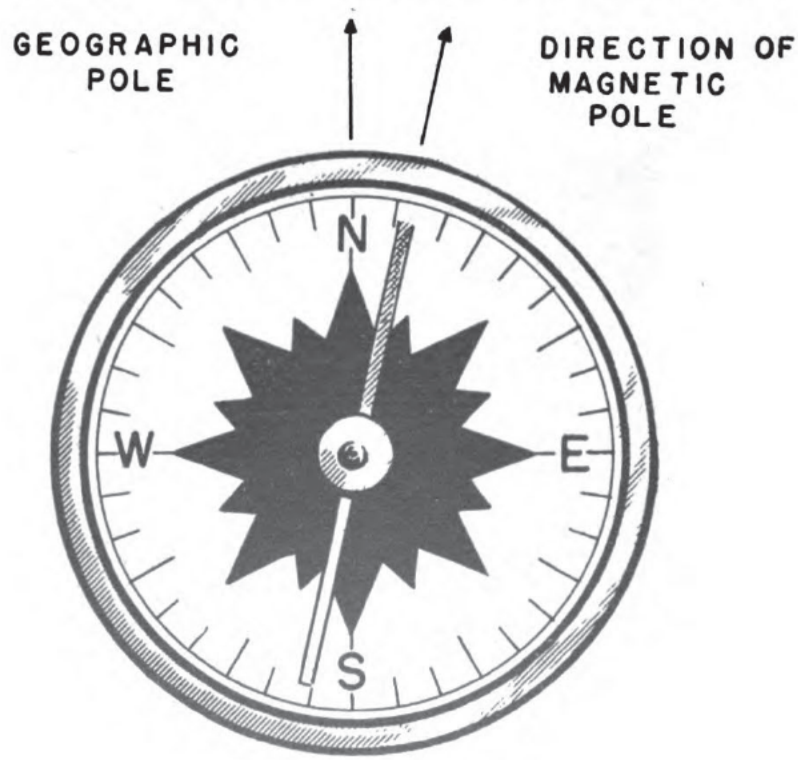


Figure 89.—The compass.

pass is a small magnet suspended on a pivot so as to be free to move horizontally and indicate direction. As you see in figure 89, the magnet lines up with its axis approximately north and south. This instrument, of course, is invaluable in navigation of ships and aircraft.

THE EARTH—HUGE MAGNET

Magnetic poles are influenced ONLY by other MAGNETIC poles. You don't have to be Sherlock Holmes to deduce, from the action of the compass, that the earth itself must be a magnet. Have a look at figure 90. The north pole of a compass is influenced to point in the general direction of the

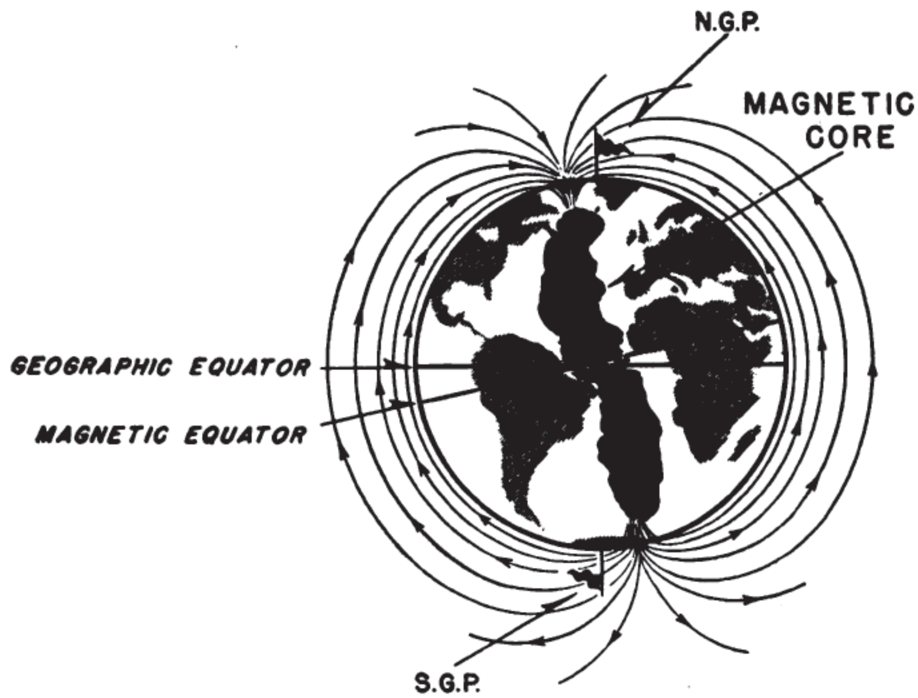


Figure 90.—Magnetic and geographic poles of the earth.

earth's north GEOGRAPHIC pole. Hence, you could gamble that somewhere in the vicinity of the north geographic pole there must be a south MAGNETIC pole. And you would win.

Although the earth's pole that attracts the north-seeking point of the compass needle is,

MAGNETICALLY speaking, a south pole, this pole is actually called the EARTH'S NORTH MAGNETIC POLE—simply because it's up north, and everybody has fallen into the habit of using the wrong scientific name. But you must remember that the earth's magnetic lines of force run from south to north.

The geographic poles of the earth are IMAGINARY, just a convenient fiction to help in designating locations on the earth's surface. They have

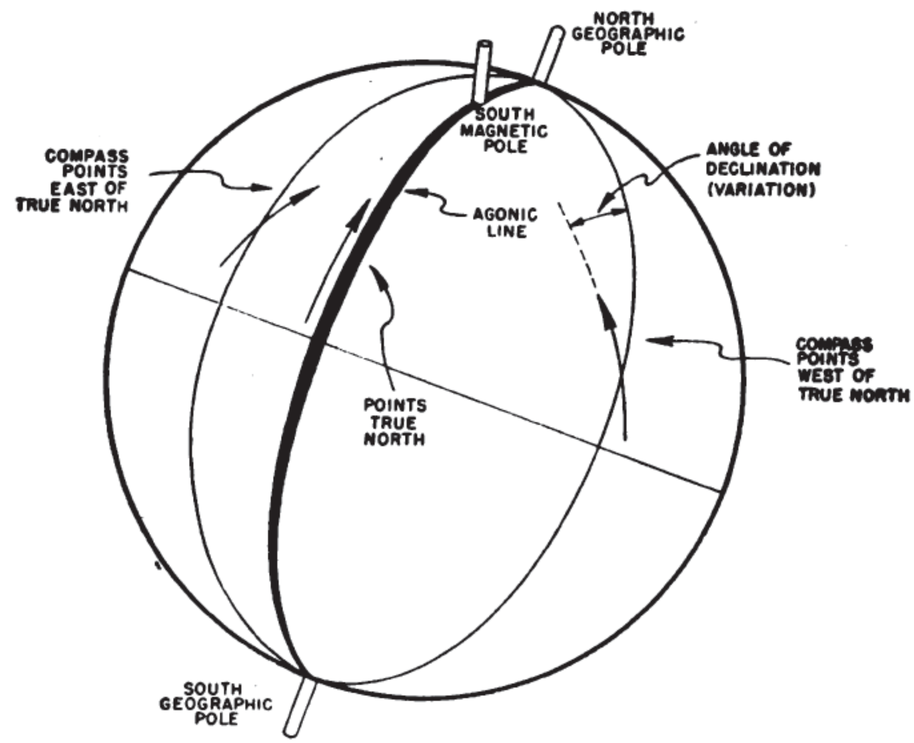


Figure 91.—Magnetic variation, or declination.

no magnetic properties. But there's nothing imaginary about the magnetic poles of the earth. THEY exhibit all the properties of true magnetic poles of any magnet.

The MAGNETIC pole up north—the so-called NORTH MAGNETIC POLE—is located north of the Hudson Bay region in Canada, and is only a short distance within the Arctic Circle, and so is NOT very near the north GEOGRAPHIC pole, in fact, is

1,400 miles south of it. Consequently, at most positions on the earth, the magnetic compass does not point true north.

The so-called SOUTH MAGNETIC POLE of the earth is on the south polar continent near South Victoria Land, almost due south of eastern Australia,

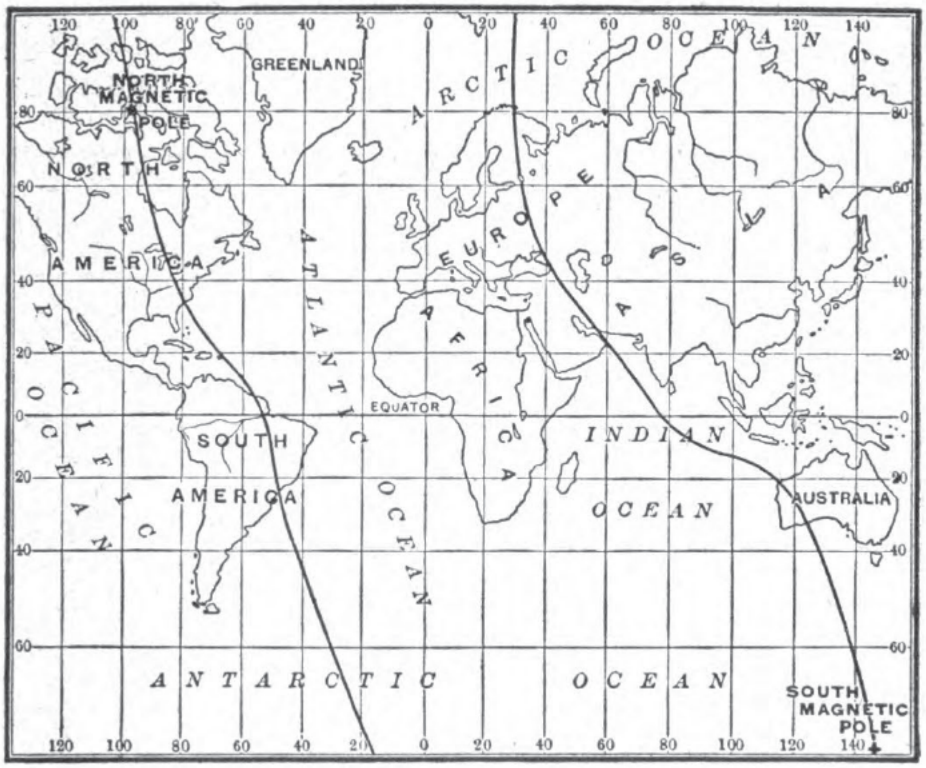


Figure 92.—Agonic line.

and some 1,250 miles north of the GEOGRAPHICAL south pole.

Figure 91 shows you that a magnetic compass points true north only in locations where the earth's magnetic poles happen to be in line with the geographic poles.

At most places on the earth, the direction in which the compass points is at an angle with a line running true north. This angle is known as the DECLINATION or VARIATION.

The points on the earth's surface where magnetic variation is ZERO may be connected by a line.

This line is known as the AGONIC LINE. But it is not as straight as drawn in figure 91. You see a somewhat more accurately drawn agonic line in figure 92. On a globe, the two lines you see in figure 92 would form a single, continuous line.

A line running through points of equal declination—that is, a line connecting points having the same angle of variation—is called an ISOGONIC LINE. You find isogonic lines on navigation

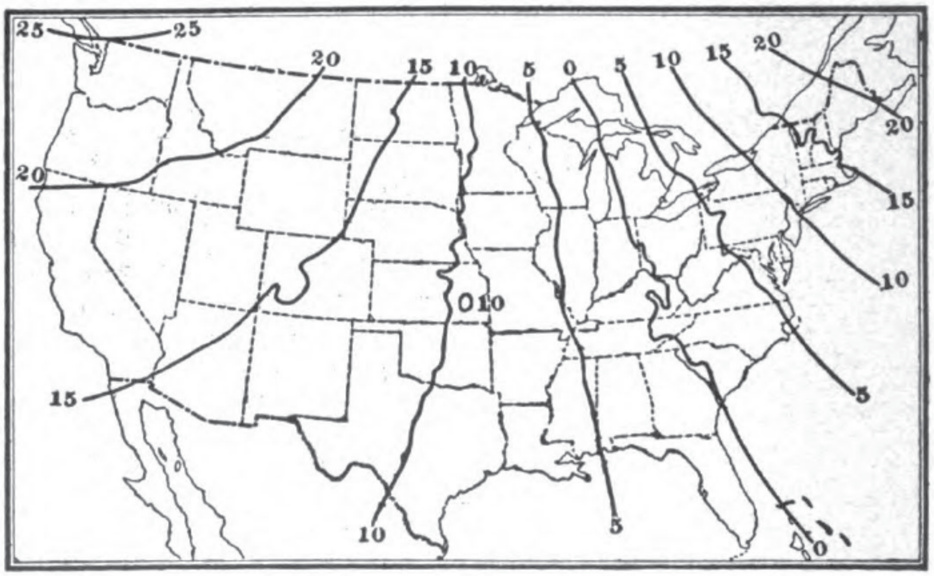


Figure 93.—Isogenic lines.

charts. In figure 93, you have a chart showing the location of isogonic lines in the United States.

CHANGES IN VARIATION

Magnetic variation itself varies. Slow, steady changes occur through the years and therefore charts showing isogonic lines must be revised every few years. Small, momentary changes in variation occur throughout each day. Sudden large changes in variation occur during MAGNETIC STORMS, which are somehow connected with sunspots or other excitement on the sun.

CORRECTING A COMPASS IN AN AIRPLANE

The compass in an airplane is influenced by any magnetic materials used in the airplane. Such errors are corrected by means of a COMPASS DEVIATION chart. Each airplane has one of these charts. The chart applies only to that particular plane, that particular compass, and that particular installation. Do not confuse compass deviation with radio direction finder deviation.

MAGNETIC INCLINATION

If a compass needle is balanced and mounted so that it can move in a vertical plane, as you see in

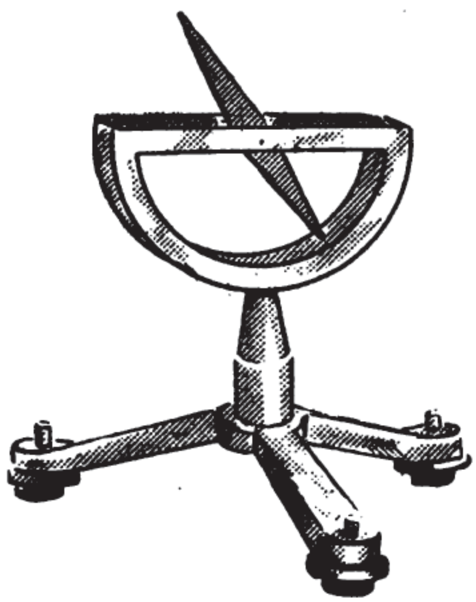


Figure 94.—Dip needle.

figure 94, the needle dips at an angle. The angle of dip will vary with the position of the needle on the earth's surface. This angle is known as the angle of INCLINATION.

A study of figure 95 shows you that, at the magnetic equator, the ends of the compass are equidistant from the magnetic poles of the earth. The attraction of the (N) pole of the compass

for the south magnetic pole of the earth is balanced by the attraction of the (S) pole of the

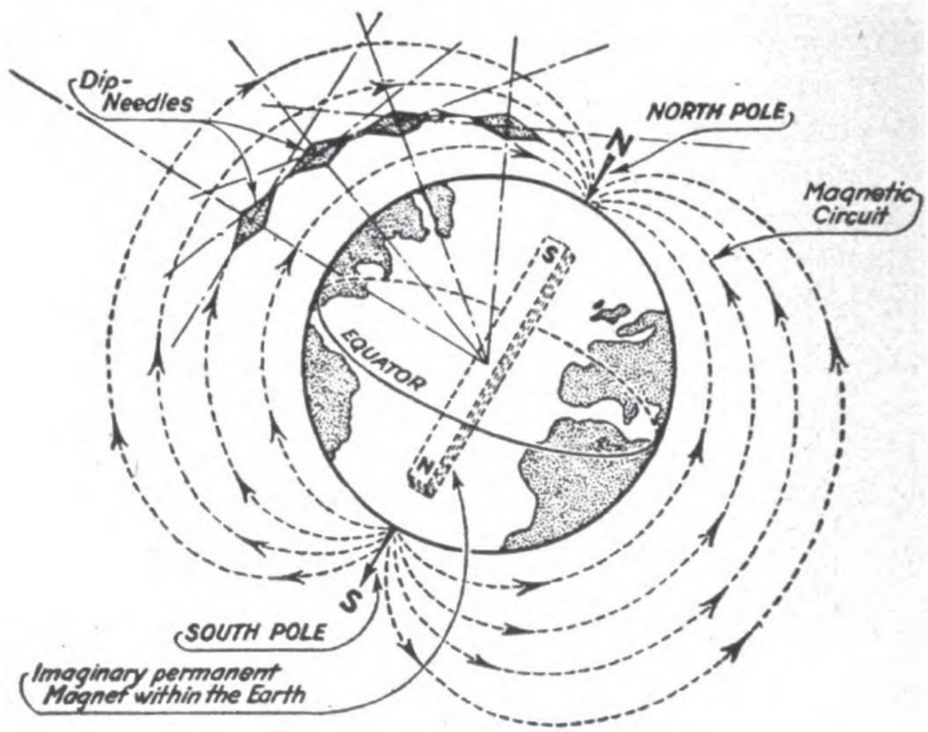


Figure 95.—Magnetic inclination.

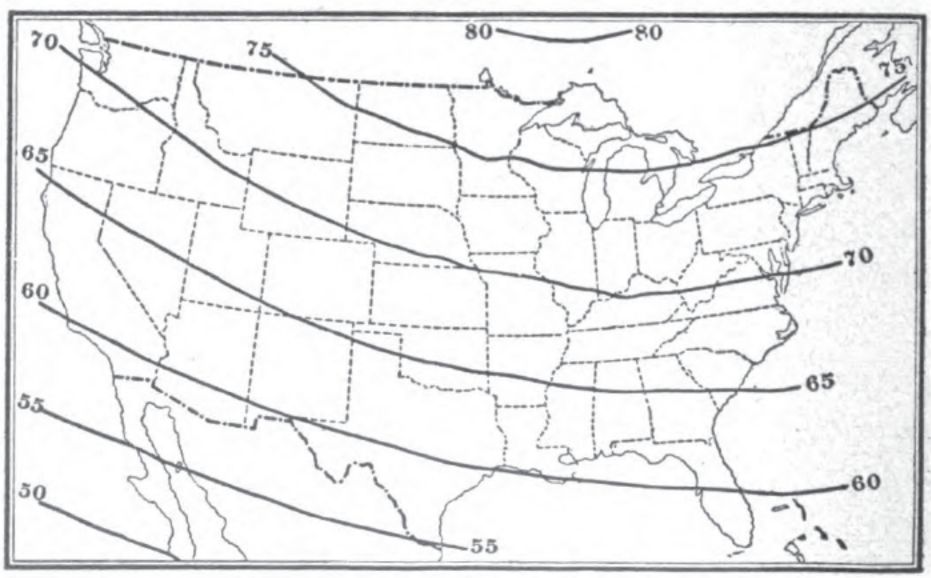


Figure 96.—Isoclinic lines.

compass for the (N) magnetic pole of the earth.
Also in figure 95, you can note the approximate position of a dip needle at various other points

on the earth's surface. In the Northern Hemisphere, the (N) pole of the compass is nearer the (S) magnetic pole of the earth and develops a tilt downward. If brought directly over the northern magnetic pole of the earth, the (N) pole of the compass points straight downward.

Lines connecting points of equal dip are known as ISOCLINIC LINES. In figure 96, you have a chart showing the location of isoclinic lines in the United States.

MAGNETIC INDUCTION

Materials that can be attracted by a magnet are known as magnetic substances. The most im-

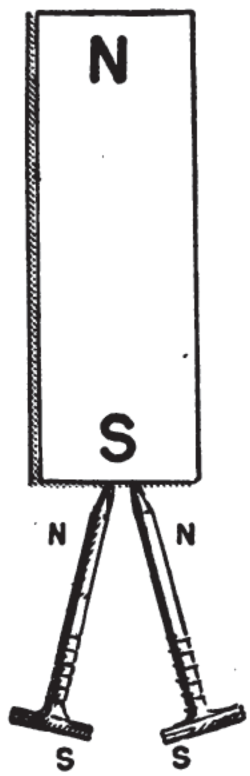


Figure 97.—Magnetic induction.

portant of these substances are the various forms of iron and steel, alloys of iron, nickel, and cobalt.

In figure 97, you see two nails hanging from a magnet. The nails themselves become magnetized

by MAGNETIC INDUCTION, and such magnets are called INDUCED MAGNETS. The nails hang in the position shown because the poles are alike at the head ends of the nails and repulsion occurs. You can hang a third nail from either of these two nails to prove that each nail is a magnet.

A magnet induces magnetism in any nearby magnetic material, and then, of course, attraction occurs according to the law of magnets. If a material is nonmagnetic, it cannot be magnetized by induction and is not attracted.

If the nails shown in figure 97 are removed from the magnet, they lose their magnetism. Nails are made of soft iron. Soft iron is easy to magnetize but it will not retain the induced magnetism. Thus, it makes only a TEMPORARY MAGNET. Hard steel is more difficult to magnetize, but once magnetized, it retains the induced magnetism and becomes a PERMANENT MAGNET. Both types of magnets are extremely useful for work in practical electricity.

MOLECULAR THEORY OF MAGNETISM

When a piece of iron is not magnetized, it is thought to have the condition pictured in figure 98. The molecules are jumbled together in a haphazard manner because of the attraction and

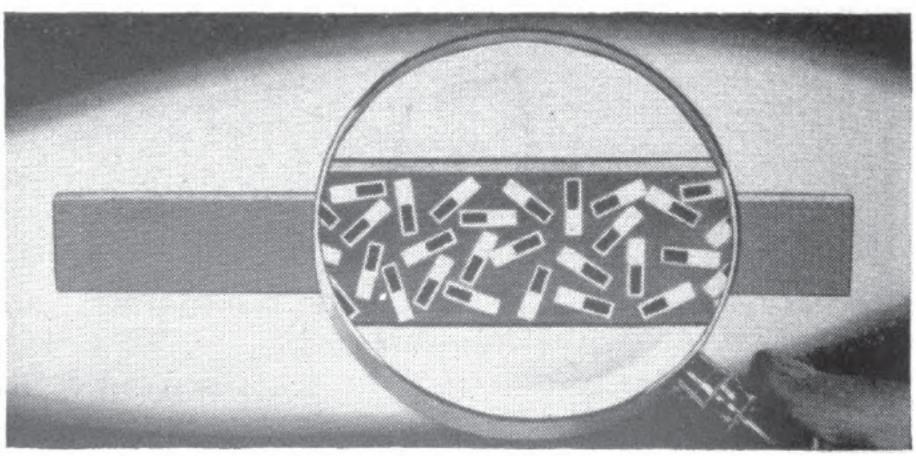


Figure 98.—Molecular magnets.

repulsion of individual molecules, which are themselves actually magnets.

When you magnetize a piece of iron, the molecular magnets line up as pictured in figure 99. All north poles face in one direction throughout the bar, and all south poles in the other direction. One end of the bar becomes the north pole of the magnet, the other end the south pole.

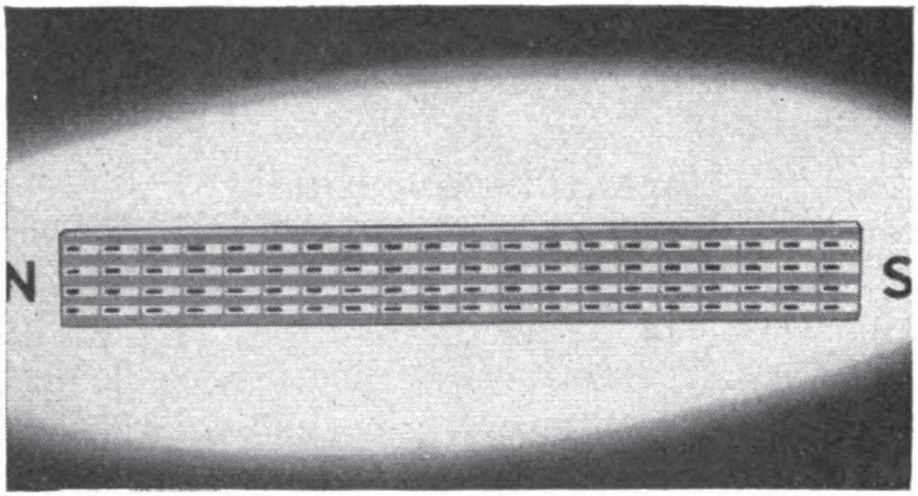


Figure 99.—Molecular alinement.

If you hammer or heat a magnet, you cause it to lose its magnetism. That is, you shake up and smack around the tiny molecular magnets and they lose their alinement.

If you break a magnet into several pieces, as shown in figure 100, you will have several magnets each with their poles in the correct positions.

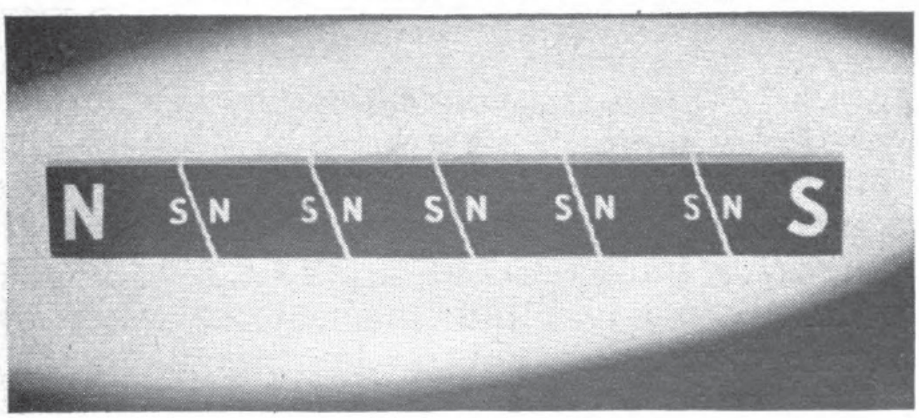


Figure 100.—Magnetic poles.

In soft iron, the molecules are easily placed in line, but the order is lost as soon as the magnetizing force is withdrawn. In hard steel, the molecules are more difficult to line up, but, once lined up, they are not readily knocked out of line.

RESIDUAL MAGNETISM

A piece of soft iron, however, does not lose all of its magnetism when the magnetizing force is withdrawn. The remaining magnetism is known as RESIDUAL MAGNETISM, important in the operation of generators.

MAGNETIZATION METHODS

All magnets are made by some sort of induction, and in all methods the molecular magnets within the material to be magnetized are brought into alinement. The magnetic strength depends on the number of molecules lined up.

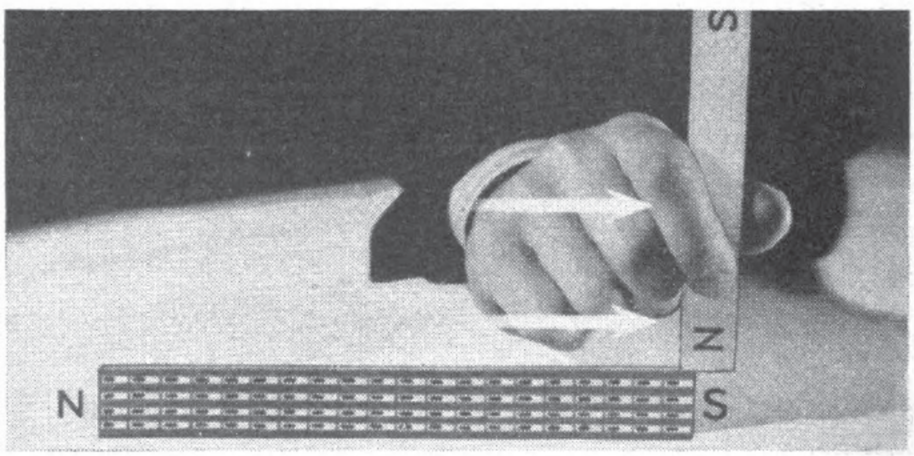


Figure 101.—Stroking method.

You can make a magnet by stroking the piece of material to be magnetized with another magnet. The stroking must be done in one direction only. You start at one end and finish at the other end. The molecular action within the piece of material is illustrated in figure 101. This method produces only a weak magnet.

In figure 102, observe another method of making a magnet. A coil of insulated wire is slipped around a piece of magnetic material, and direct

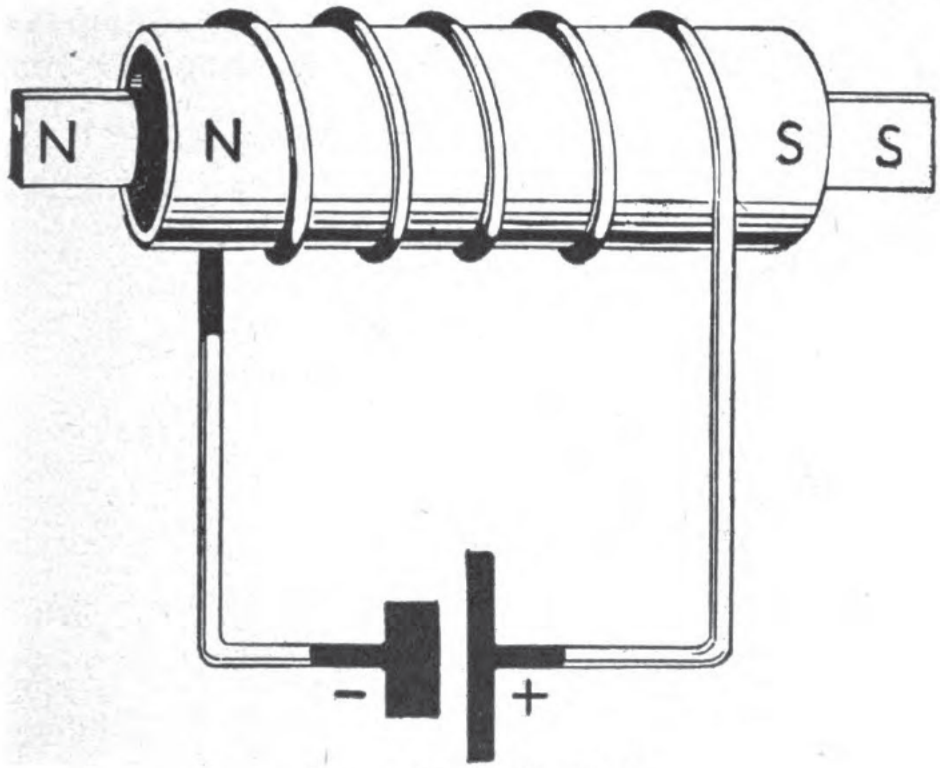


Figure 102.—Coil method.

current is sent through the coil. The piece of material within the coil becomes strongly magnetized by this method.

The simplest, quickest, and most efficient method of making or remaking magnets is through the use of a MAGNETIC CHARGER diagramed in figure 103. The word "charger" is a term used by electricians but is somewhat misleading. This device does no real "charging." It merely lines up the molecular magnets.

A magnetic charger is a powerful two-pole electromagnet with open jaws (poles). The material to be magnetized is placed across the jaws. Then you apply direct current and hammer the material. This hammering jars the molecular magnets and so aids their lining up.

Magnetic flux passes through any material known. There is NO known insulator of magnetic flux. Now, lines of force pass through magnetic materials, such as soft iron, with greater ease than

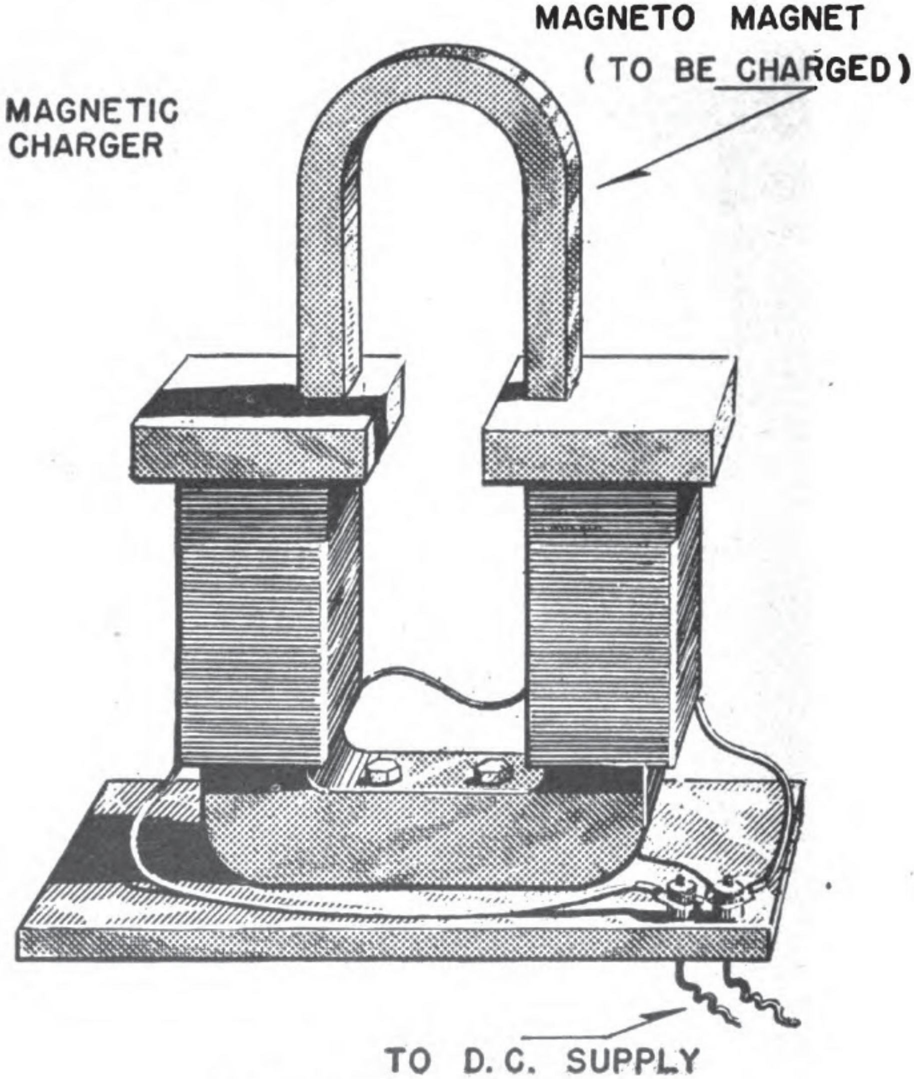


Figure 103.—The magnetic charger.

through air. The readiness with which magnetic flux passes through a substance is known as the PERMEABILITY of that substance.

In figure 104, note the effect of placing a piece of soft iron in the field of a permanent magnet.

The lines of force are deflected so as to pass through the iron because the iron is a better carrier of flux than air. In other words, the iron has less magnetic resistance.

In the case of generators and motors, permeability is very important. You have to build up large amounts of magnetic flux. The paths for flux must have low magnetic resistance, or high permeability, if you are to have large amounts of flux. The same magnetizing force that sets up

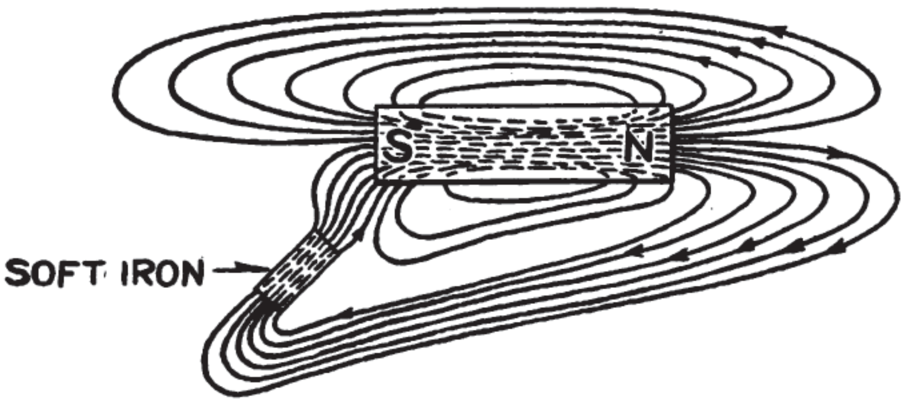
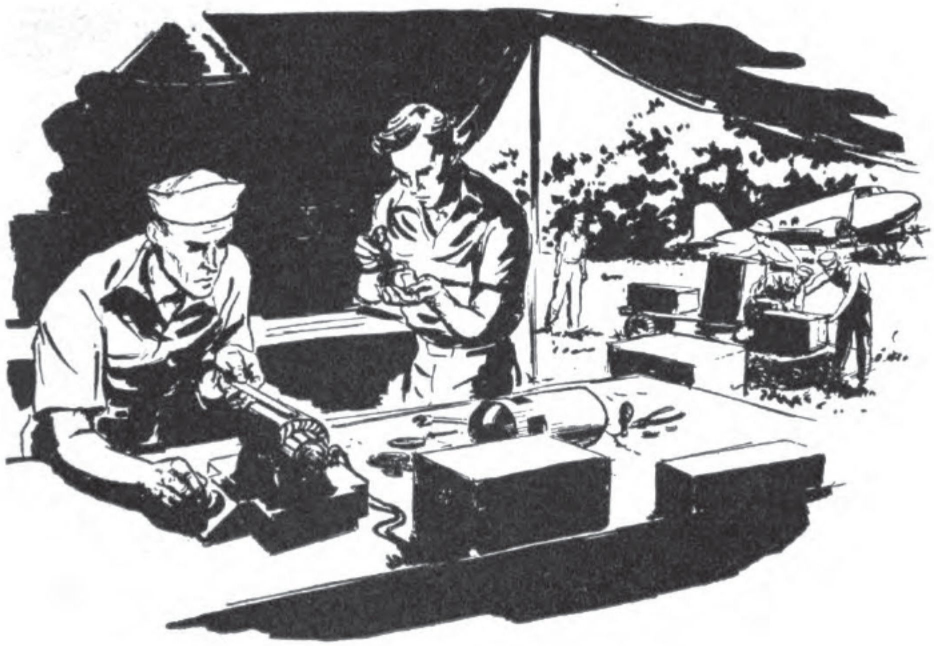


Figure 104.—Permeability of iron.

one line of force in air would set up as much as 1,000 lines of force in certain types of iron. So, air gaps in generators and motors are made as small as possible.

RELUCTANCE vs. PERMEABILITY

The magnetic resistance offered by a material to the passage of magnetic flux is also known as RELUCTANCE. Reluctance is the OPPOSITE of permeability. Thus iron and other magnetic materials have low reluctance. Air and nonmagnetic materials have high reluctance.



CHAPTER 11

ELECTROMAGNETISM

FIELD AROUND A CONDUCTOR

An electric current is always accompanied by a magnetic field.

Dip a current-carrying conductor into iron filings. As you see in figure 105, the filings cling to the conductor throughout its length. Break the circuit, and the filings drop from the conductor. The magnetic field is present only when current flows.

You can discover the general pattern of the magnetic field around a current-carrying conductor by means of iron filings and a cardboard sheet with a hole in it. In figure 106, you find a diagram of the arrangement. Sprinkle filings on the cardboard, and tap it while current is flowing. You observe that the filings line up in concentric circles around the current. This circular magnetic field is present ALONG THE ENTIRE LENGTH OF ANY CONDUCTOR CARRYING AN ELECTRIC CURRENT.

Figure 105.—An electric current is accompanied by a magnetic field.

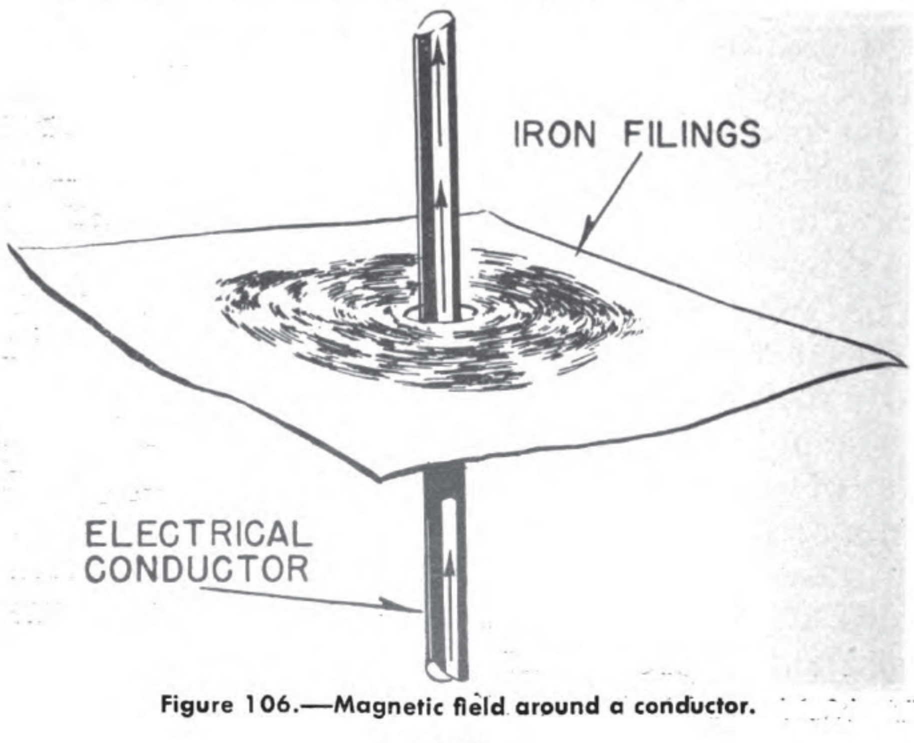


Figure 106.—Magnetic field around a conductor.

DIRECTION OF THE MAGNETIC FIELD

You can easily find the direction of the magnetic field around the current by placing small compasses on the cardboard, as in figure 107. Of course, if no current is flowing through the conductor, the compasses point north. When the current flows, the compass needles swing around and indicate a circular magnetic field. Now, re-

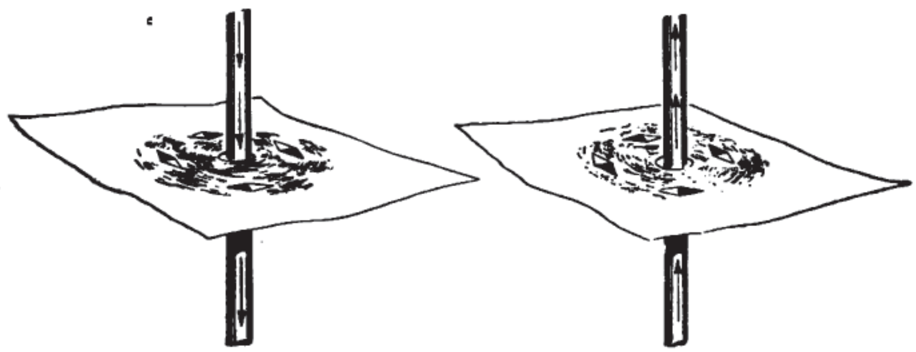


Figure 107.—Flux direction about a conductor.

verse the current, and the compass needles also reverse their direction.

So you see that, by use of a current, it is possible to set up a magnetic field and to control its direction.

ARROW TRICK OF MARKING CURRENT DIRECTION

In (*A*) of figure 108, you have a conductor with current flowing toward you. Note the use of the symbol ⊙. It represents the tip, or pointed end, of an imaginary arrow in flight in the same direction as the current.

In (*B*) of figure 108, you have a conductor with the current flowing away from you. The symbol ⊗ represents the feathered end of an imaginary arrow, again in flight in the direction of the current.

In figure 109, note the end views of the magnetic flux and its direction around a current-

carrying conductor. Also note that the position magnetic compasses take in this field is ACCORDING

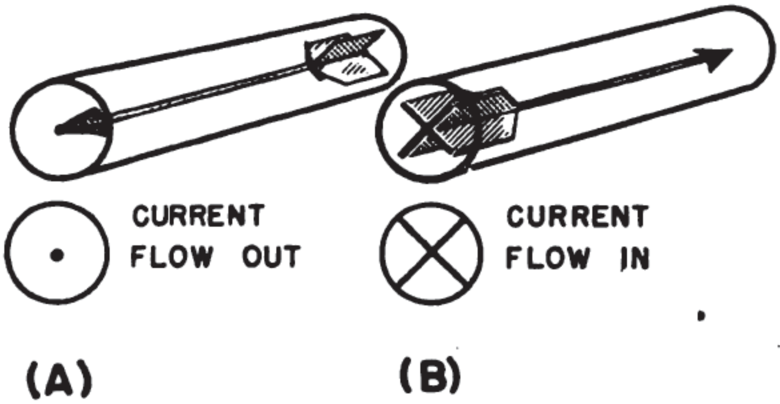


Figure 108.—Dot-cross method of indicating current direction.

TO THE DIRECTION OF THE CURRENT. Where is the magnetic field strongest? Obviously, close to the conductor. The amount of flux—that is, the

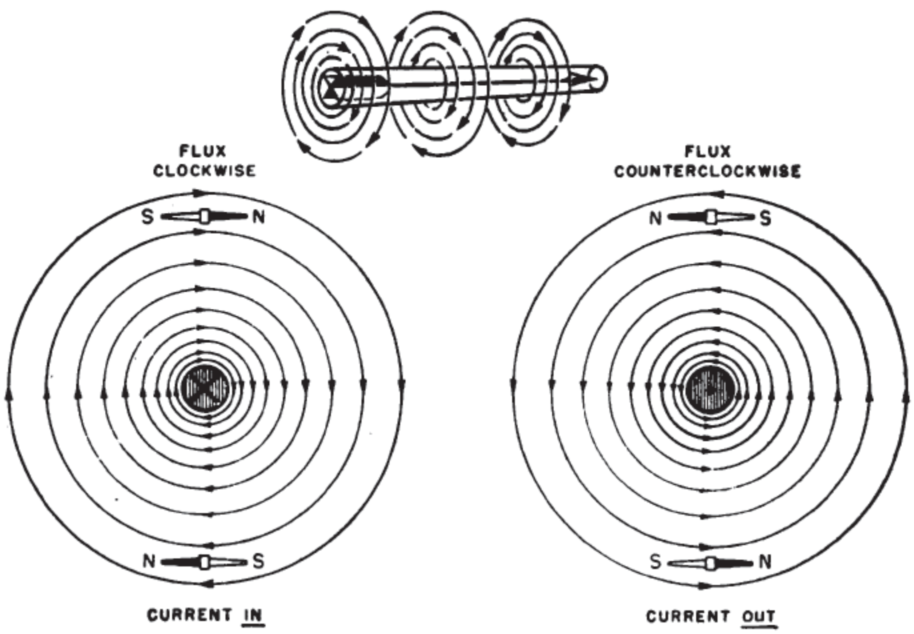


Figure 109.—Flux direction—cross-sectional view.

strength of the field—decreases as the distance from the center of the wire increases.

THE RIGHT-HAND RULE

When the direction of the CURRENT in a conductor is KNOWN, you can tell the direction of the

FLUX about the conductor by the RIGHT-HAND RULE. See figure 110.

GRASP THE WIRE IN YOUR RIGHT HAND WITH YOUR THUMB POINTING IN THE DIRECTION OF THE

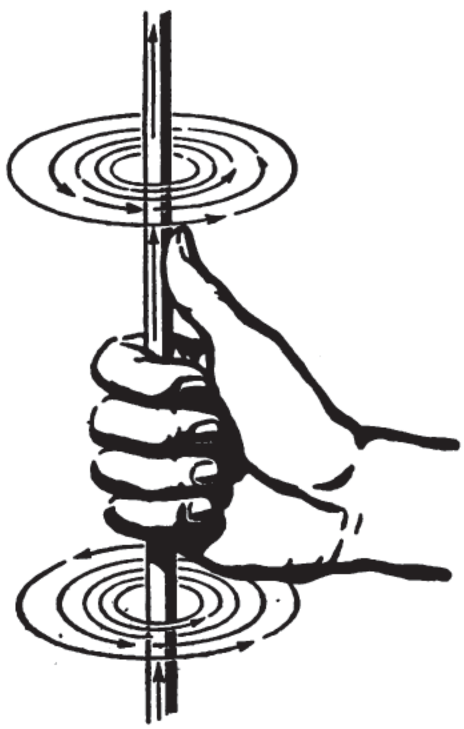


Figure 110.—Right-hand rule—conductor flux.

Figure 111.—Determining current direction.

CURRENT. YOUR "FINGERS" WILL THEN POINT IN THE DIRECTION OF THE FLUX.

By use of a compass AND the converse of the right-hand rule, you can find out the direction of the CURRENT in a conductor. See figure 111.

GRASP THE WIRE WITH YOUR "FINGERS" POINTING IN THE SAME DIRECTION AS THE COMPASS

NEEDLE. YOUR "THUMB" WILL THEN POINT IN THE DIRECTION OF THE "CURRENT."

MAGNETIC POLARITY

A magnet, as you know, has at least two poles where lines of magnetic force are concentrated. Magnetic flux emerges from the NORTH pole, and enters the magnet at the SOUTH pole.

A straight wire carrying a current has a magnetic field. But there are no points where flux emerges or enters, hence there are NO poles.

Now make a loop out of a current-carrying conductor, and as you see in figure 112, magnetic poles are set up.

Note that the north pole lies in the space in front of the right-hand face of the loop, and the south pole is in the space in front of the left-hand face of the loop. In the center of the loop, flux from all parts of the loop is in one direction.

In figure 113, you see a series of loops—that is, a COIL carrying a current. Each loop contributes some magnetic flux, and the lines of force merge so that they pass along the axis through the entire coil. The flux emerges at one end of the coil and a NORTH pole is located there. You find a SOUTH pole where the flux enters the coil, at the opposite end.

As you would naturally guess, the magnetic polarity of the coil depends on the direction of the current in the coil. When the direction of the CURRENT is KNOWN, you can find the north pole—and then, of course, the south pole—by means of the RIGHT HAND RULE FOR COIL POLARITY. See figure 114.

PALM AND EXTENDED FINGERS OF YOUR "RIGHT" HAND ARE AT RIGHT ANGLES. PLACE YOUR HAND

SO THAT THE FINGERS ARE INSIDE THE COIL AND THE "THUMB" IS ON THE END TURN IN THE SAME

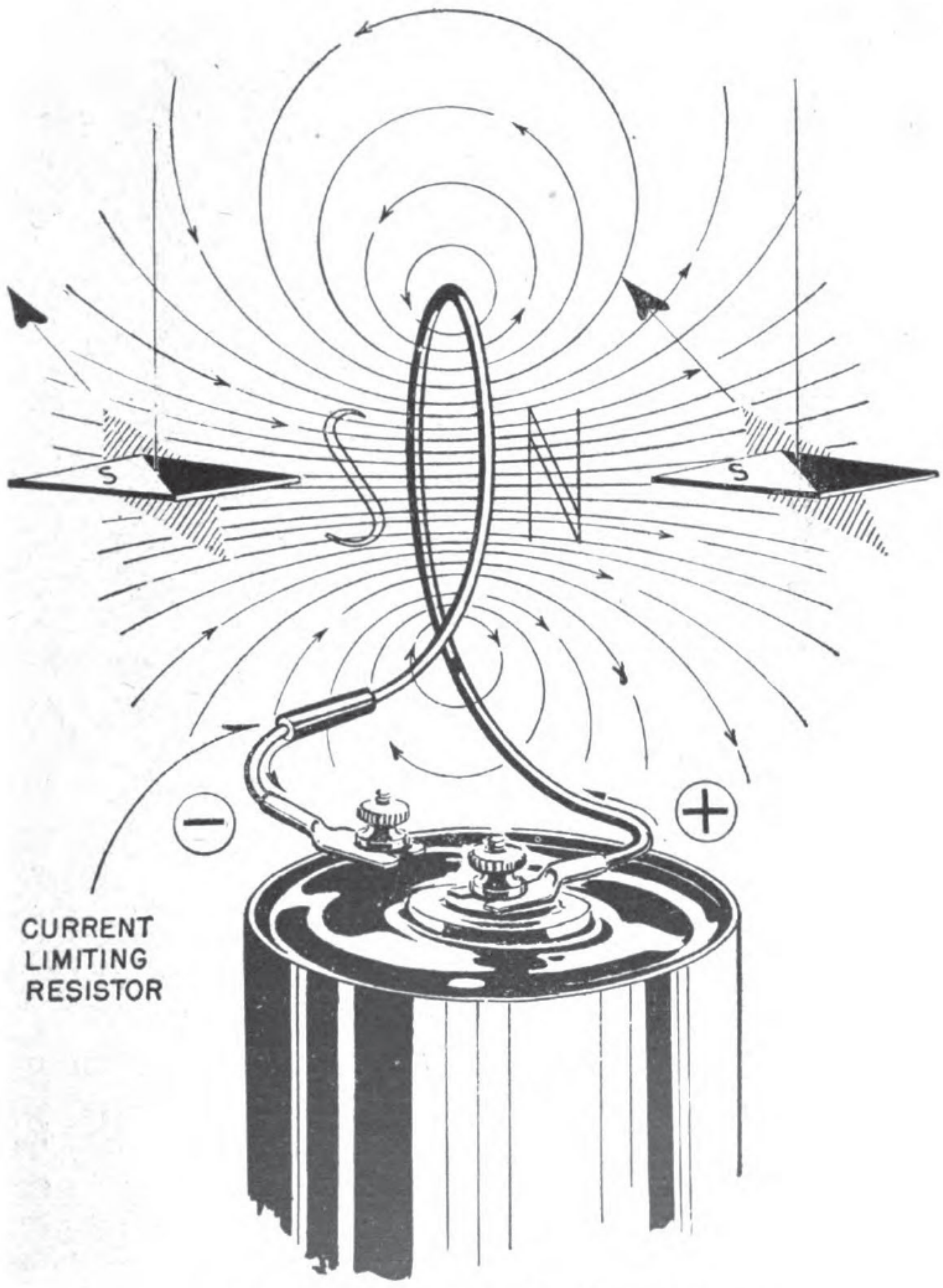


Figure 112.—Magnetic polarity of a loop.

DIRECTION AS THE "CURRENT." YOUR "FINGERS" WILL THEN POINT TO THE "NORTH" POLE.

You MUST understand the application of the right-hand rule for coil polarity. Test your understanding by means of the problems in figure 115 on page 150.

In problems (*a*), (*b*), (*c*), and (*d*), see if you can determine the polarity of each coil end that is marked with a question mark. You can apply the rule more easily if you mark the current direction on the turns that are exposed to view on the front of the coil.

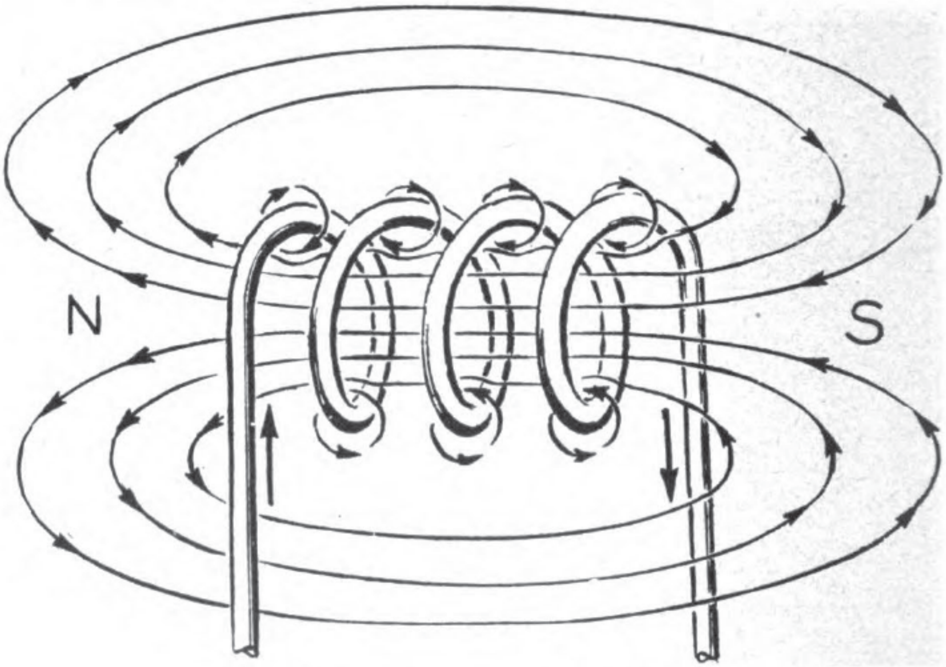


Figure 113.—Magnetic polarity of a coil.

In problems (*e*), (*f*), (*g*), and (*h*), the magnetic polarity of each coil is marked. But the coils will have this polarity ONLY IF you make the proper connection to the battery. Note that one of the leads to each coil is marked with an *X*. The question is which battery terminals should be connected to the leads marked *X*?

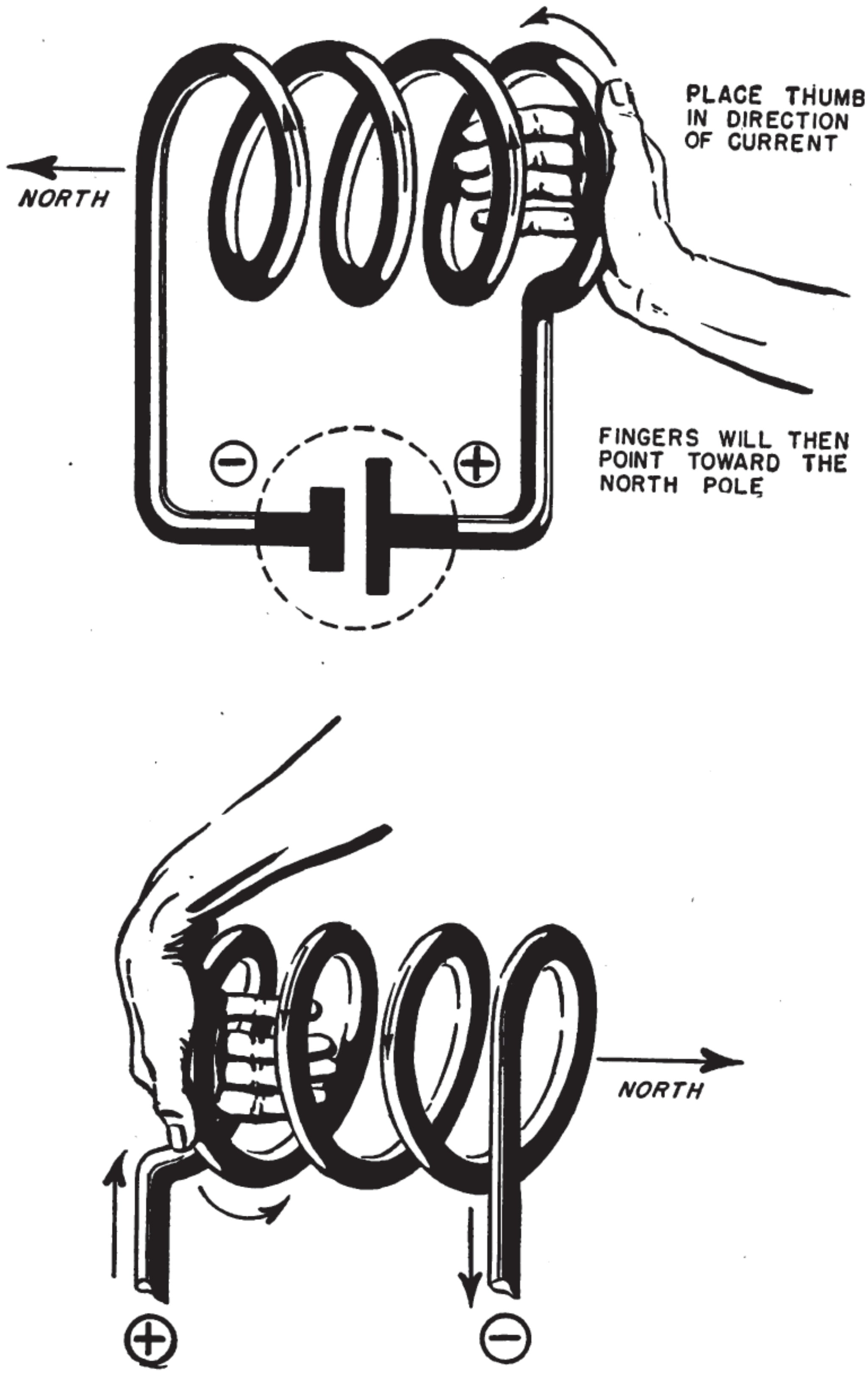


Figure 114.—Right hand rule for coil polarity.

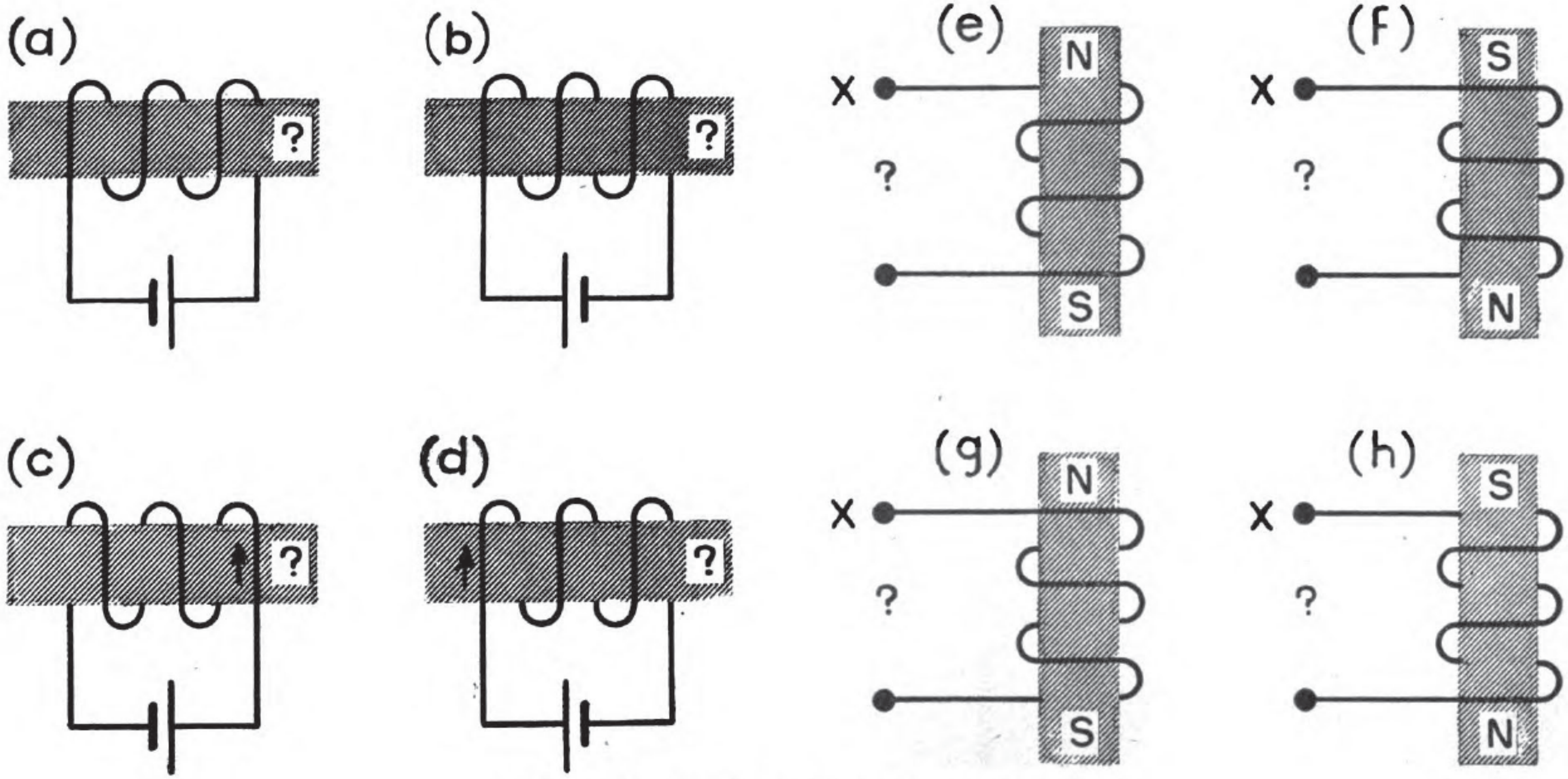


Figure 115.—Application of the right-hand rule.

Here are the answers to the problems. HEY! NO PEEKING! Work out YOUR answer BEFORE you look.

(*a*) North	
(*b*) South	
(*c*) South	
(*d*) South	

(*e*)	X to Negative
(*f*)	X to Negative
(*g*)	X to Positive
(*h*)	X to Positive

When you add more turns to a coil, MORE lines of force are created and hence a STRONGER magnetic field.

When you INCREASE the strength of the CURRENT, you INCREASE the strength of the MAGNETIC FIELD.

CONCLUSION—

Magnetic strength of a coil depends on the number of turns, and the strength of the current.

SOME SIMPLE MATHEMATICS ARE IN ORDER—

The magnetic strength of a coil is PROPORTIONAL to the number of amperes and the number of turns. Multiply the amperage (I) by the number of turns (N) and you get the product known as ampere-turns, or NI.

A 20-turn coil has a current of 5 amperes. What does NI equal? Obviously, the ampere-turns equal 20 times 5, or $NI=100$.

Suppose it was a 100-turn coil. Then $N=100$. And a current of only 1 ampere would be required to have $NI=100$.

Therefore, a 20-turn coil with a 5-ampere current has a magnetic field of the same strength as a 100-turn coil with a 1-ampere current.

When you place a soft iron CORE inside a current-carrying coil, you prevent magnetic leakage

between turns and concentrate the flux. The flux from the coil lines up the molecular magnets within the iron so as to make a POWERFUL magnet.

Here's a new term for you—SOLENOID, meaning nothing more than a coil of wire used to set up a magnetic field. All solenoids have a core, whether or not you can see the core as in figure 116. Look-

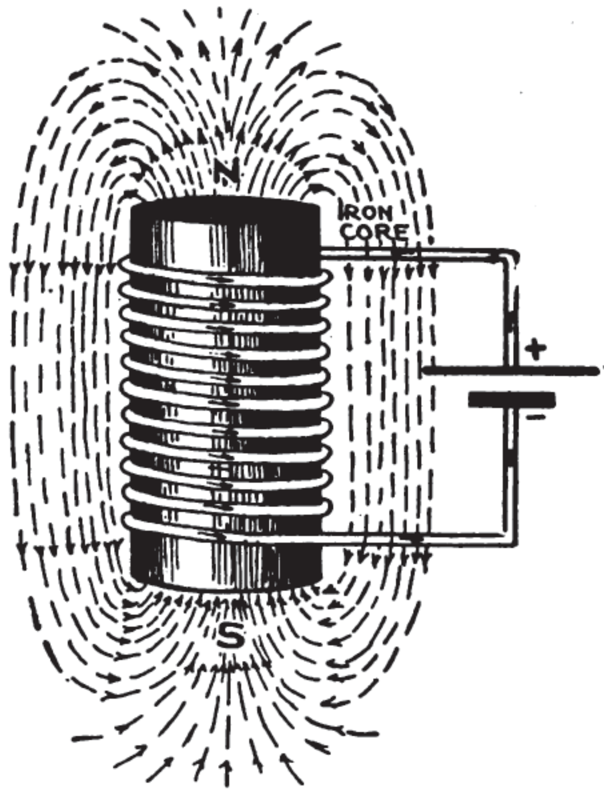


Figure 116.—Iron core solenoid.

ing back to figure 113, you find that there you have an invisible core—of AIR. Hence you have an AIR CORE SOLENOID in figure 113.

Here's still another term—ELECTROMAGNET, meaning a magnet whose lines of force are set up by an electric current. A solenoid and an electromagnet are one and the same.

Because of its permeability, SOFT IRON is used as the core of an electromagnet when high magnetic strength is required.

Electromagnets are indispensable in practically all electrical equipment, including radios, genera-

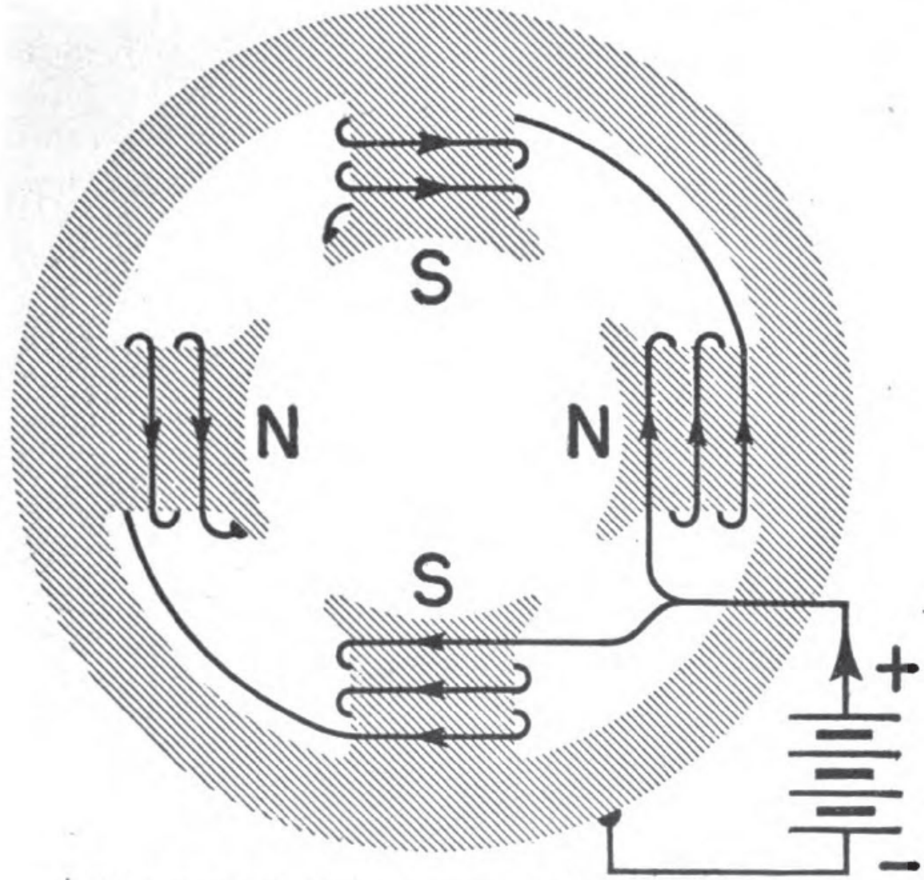


Figure 117.—Magnetic polarity of the field poles of a motor.

tors, and motors. In figure 117, you see a diagram of the field magnets of a motor.

CIRCUIT BREAKERS

A circuit breaker, like a fuse, protects a circuit against short circuits and overloading. In this device, you have an electromagnet whose winding is in series with the load circuit to be protected and with the switch contact points. Excessive current causes the magnet to trip a switch that breaks the circuit to both breaker and load. When the circuit fault has been cleared, the circuit is closed again by resetting the circuit breaker.

In the INTERRUPTER type circuit breaker, figure 118, the circuit is only momentarily broken whenever there is a short circuit or overload. When the current is too high, the electromagnet becomes strong enough to attract the iron ARMATURE and so breaks the circuit—hence cuts its own current. The electromagnet loses its magnetism and ceases

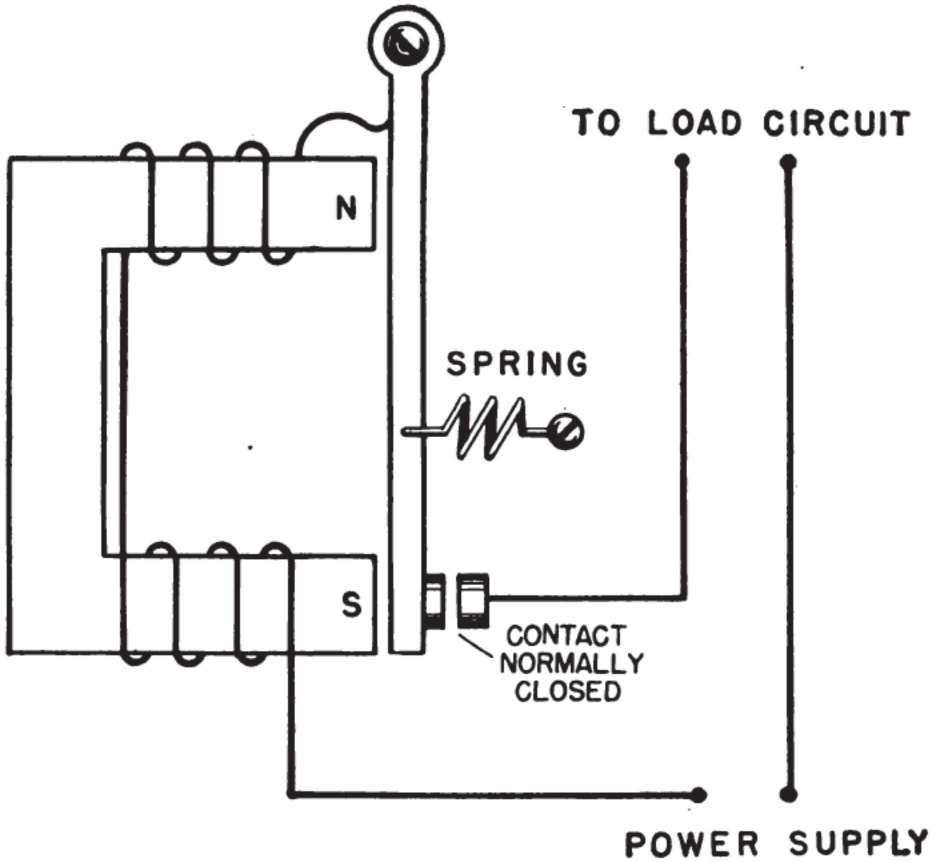


Figure 118.—Interrupter type circuit breaker.

to attract the iron armature. A spring immediately closes the circuit, which may be broken again, if the circuit fault has not been cleared. Thus there may be a series of interruptions occurring at a rapid rate until the circuit burns clear or someone corrects the difficulty. These interruptions make a buzzing sound which serve as an alarm.

CHAPTER 12

GENERATORS

INDUCING ELECTROMOTIVE FORCE

Connect a sensitive voltmeter, or galvanometer, to the ends of a conductor, such as a copper wire, and move the conductor downward through a magnetic field, so that it CUTS MAGNETIC LINES OF FORCE, as you see in figure 119. The galvanometer shows a slight deflection to the right, proof that ELECTRONS ARE INDUCED TO FLOW ALONG A CONDUCTOR WHEN IT CUTS MAGNETIC LINES OF FORCE. In other words, you have an induced emf, or voltage, within the wire, and this electromotive force causes a flow of current. Note the direction of the current.

Now move the conductor UPWARD through the magnetic lines of force, as in figure 120.

Note the galvanometer is again deflected, BUT this time to the LEFT. The direction of the current depends upon the direction of movement of the conductor through the magnetic field.

The direction of the magnetic field is a factor, too. Examine figure 121. Reverse the magnetic field, and you reverse the direction of the current.

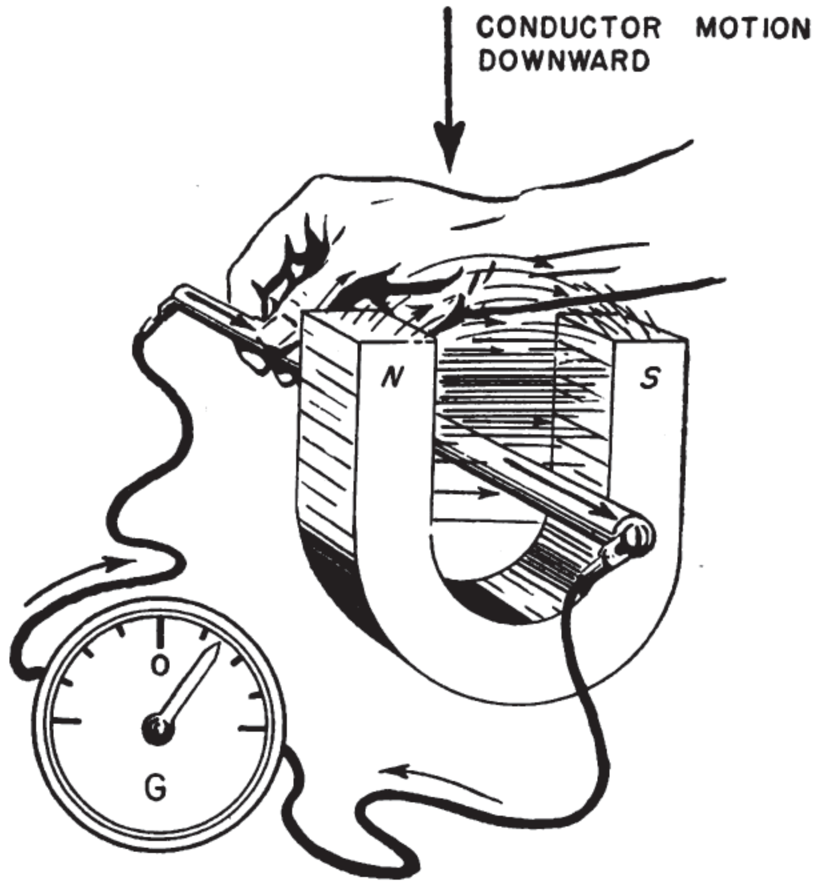


Figure 119.—Inducing electromotive force.

So, direction of induced emf is dependent upon BOTH the direction of the movement of the conductor, and the direction of the magnetic field.

RIGHT-HAND CATCH RULE

In figure 122 you have the right-hand catch rule for finding the direction of induced emf when you know the direction of the magnetic flux and the direction of movement of the conductor.

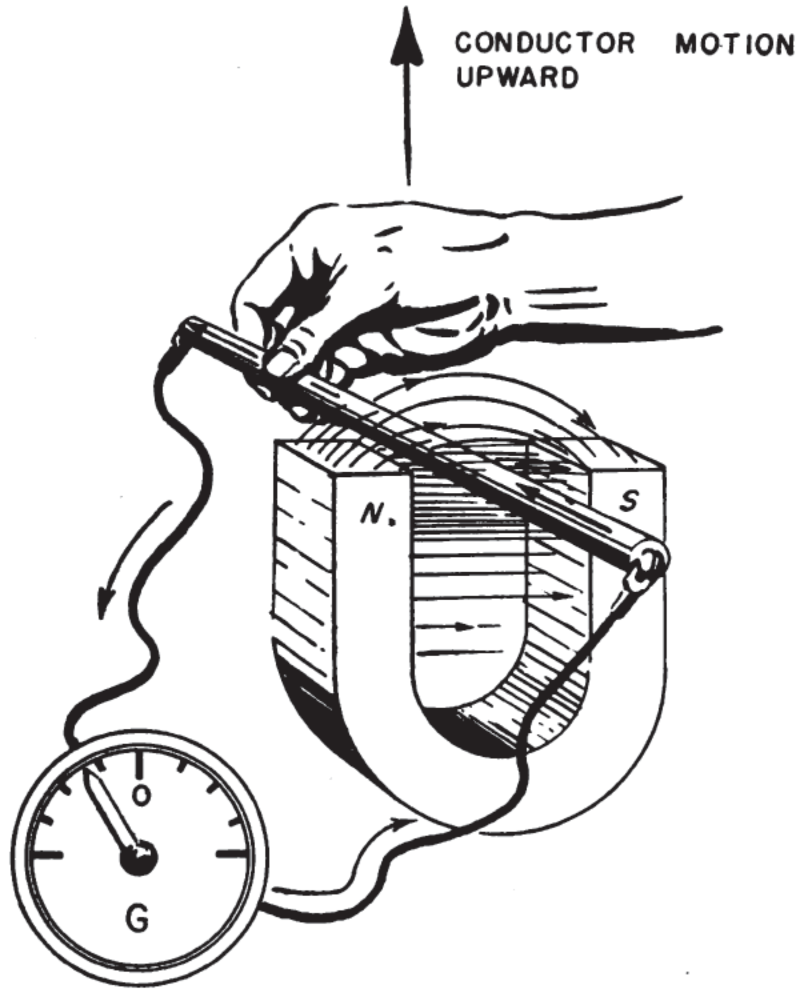


Figure 120.—Direction of induced current depends upon direction of movement of conductor.

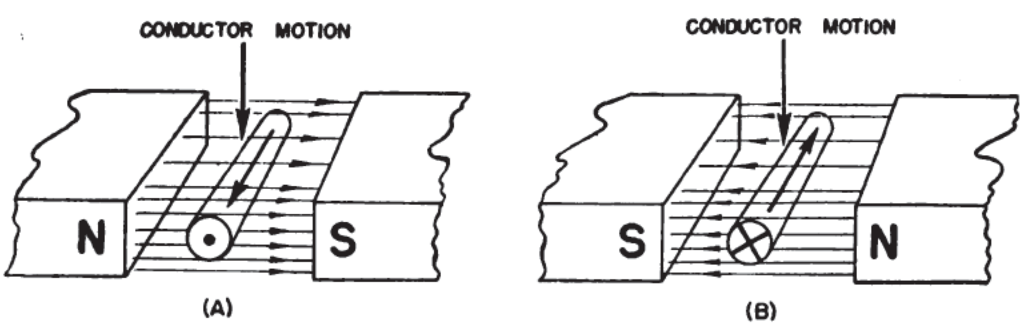


Figure 121.—Magnetic field reversed, current reversed.

PLACE THE "RIGHT" HAND AS THOUGH TO "CATCH" THE CONDUCTOR IN ITS MOTION. ALSO THE OUTSTRETCHED FINGERS MUST POINT IN THE DIRECTION OF THE MAGNETIC LINES OF FORCE.

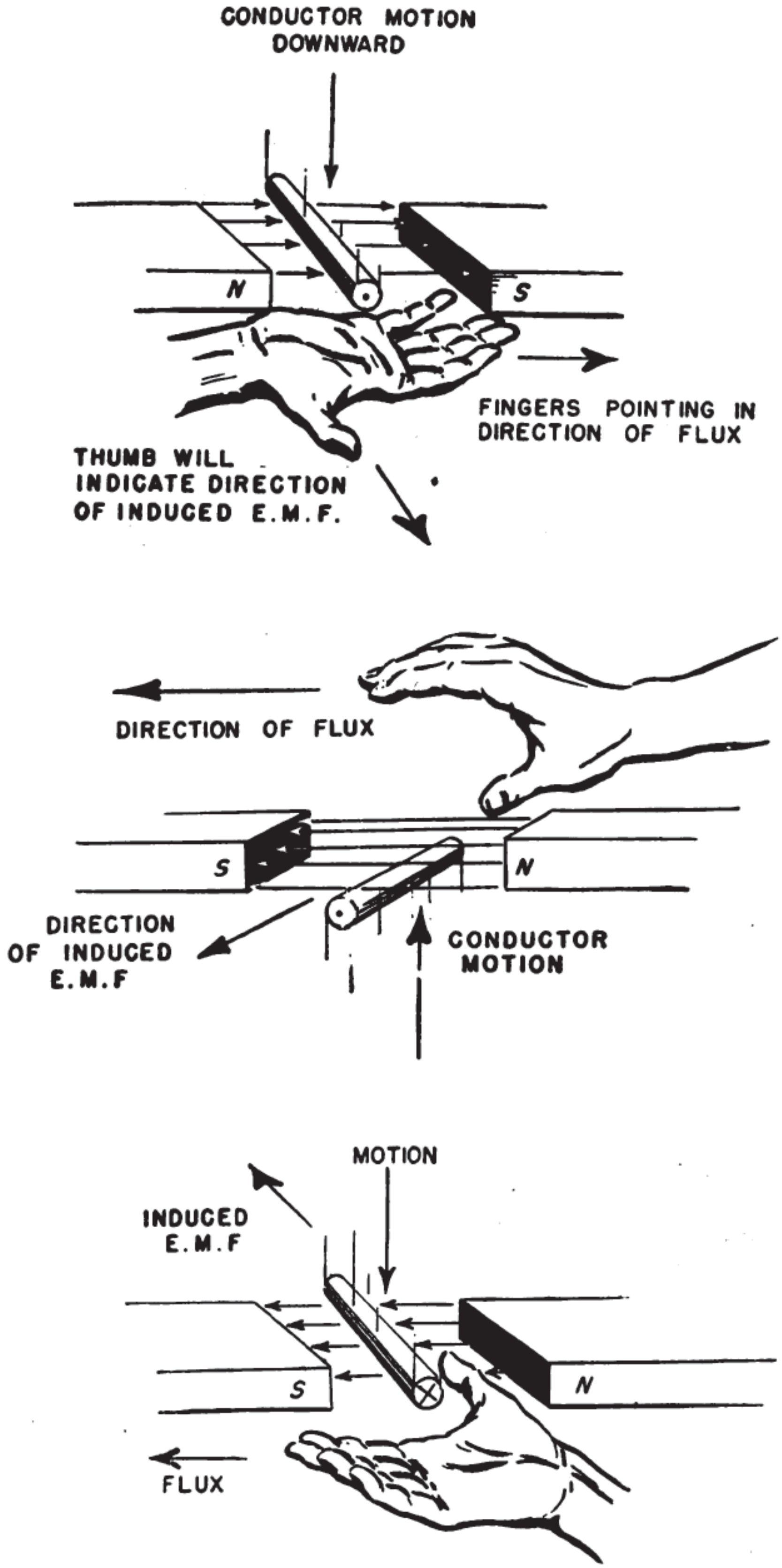


Figure 122.—Determining direction of induced voltage.

THE "THUMB" WILL THEN POINT IN THE DIRECTION OF THE INDUCED EMF.

Increase the SPEED of a conductor moving through a magnetic field, and you increase the emf.

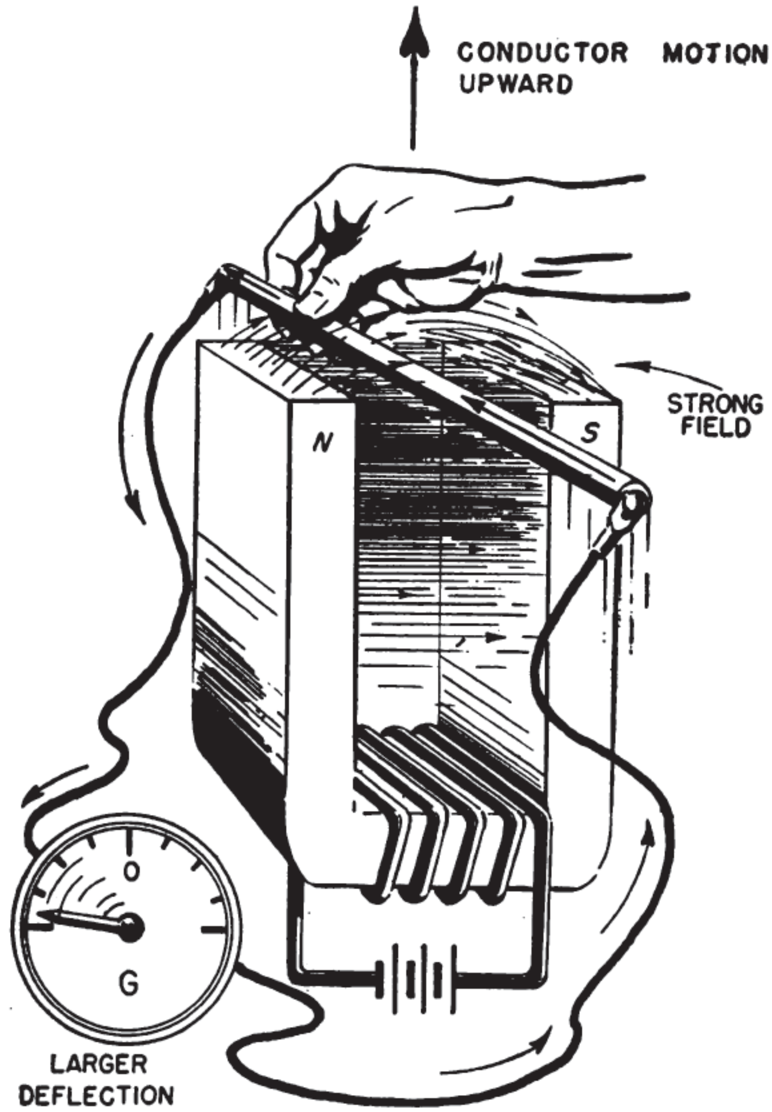


Figure 123.—Effect of strengthening the magnetic field.

Increase the strength of the magnetic field, and, if the conductor moves through the field at the same speed, you again increase the emf.

THE STRENGTH OF THE EMF DEPENDS UPON THE NUMBER OF LINES OF FORCE CUT PER SECOND. The

greater the number of magnetic lines of force cut per second, the greater the emf.

EMF INDUCED IN A LOOP

In figure 124 you have a one-turn loop rotating in a CLOCKWISE direction at uniform speed through a magnetic field. To help you to find the direction of the induced current, the loop is divided into two parts. One half is black, and the other half is white. Note that when no part of

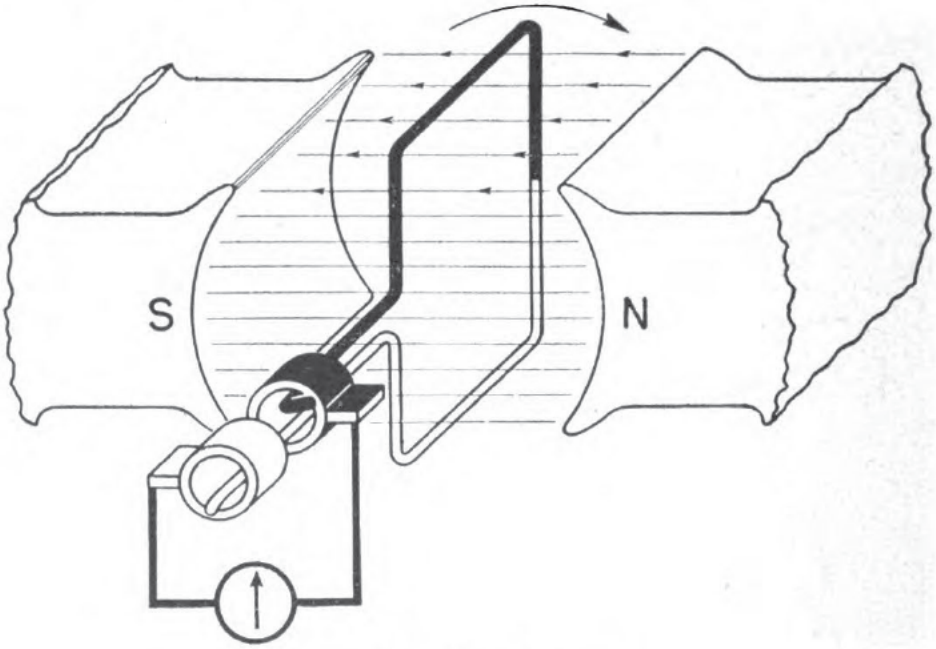


Figure 124.—Rotating loop—1.

the loop is cutting lines of force the induced emf is zero. The sides of the loop are at this time moving parallel to the magnetic field.

Soon the black half of the loop passes by the north pole, and the white half by the south pole, as you observe in figure 125. Both parts of the conductor cut across the magnetic field and an emf is induced in both. Apply the right-hand catch rule, and you discover that the induced currents flow in opposite directions on opposite sides

of the loop. BUT this means that, in the loop as a WHOLE, the currents are in the SAME direction.

Take note of the device used to lead off the current induced in the loop—each end of the loop is connected to a ring, or slip ring. The two rings are separate, and no short circuit exists between them. A brush makes contact with each ring, and the external circuit leads from one brush back to

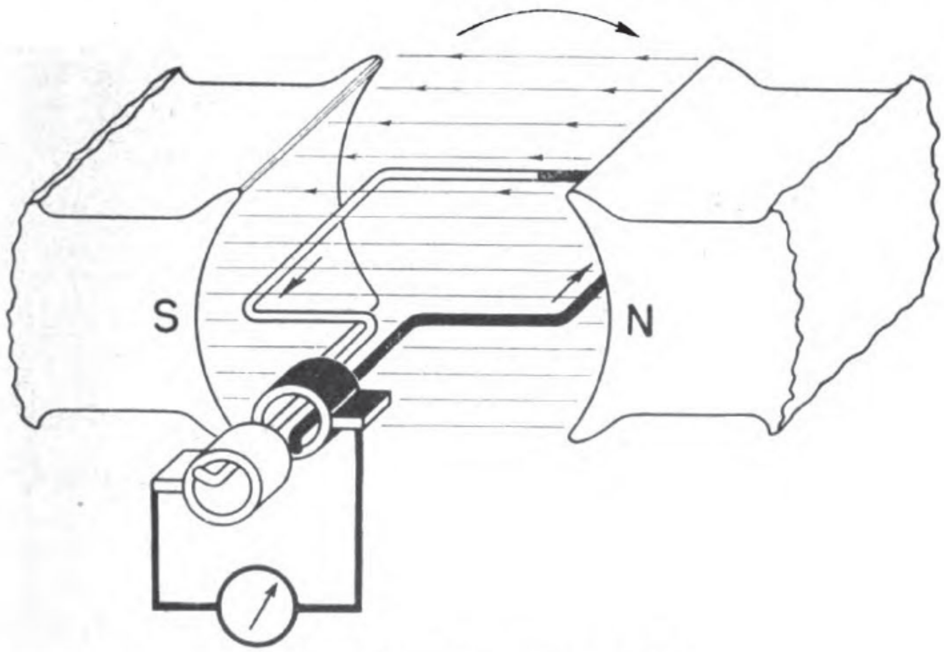


Figure 125.—Rotating loop—2.

the other. Hence, the current has a complete path through which it may flow.

Continue to rotate the loop, still in the CLOCKWISE direction, and it comes to the vertical position you have in figure 126. In this position, obviously the loop is again moving parallel with the lines of force and does not cut them. Again the induced emf is ZERO.

Soon the black half of the loop passes by the south pole, and the white half by the north pole, as you observe in figure 127. The black part of the conductor is now moving upward. The white part moves downward. Again apply the right-hand

catch rule to each side of the loop, and you will note that the direction of the induced emf has

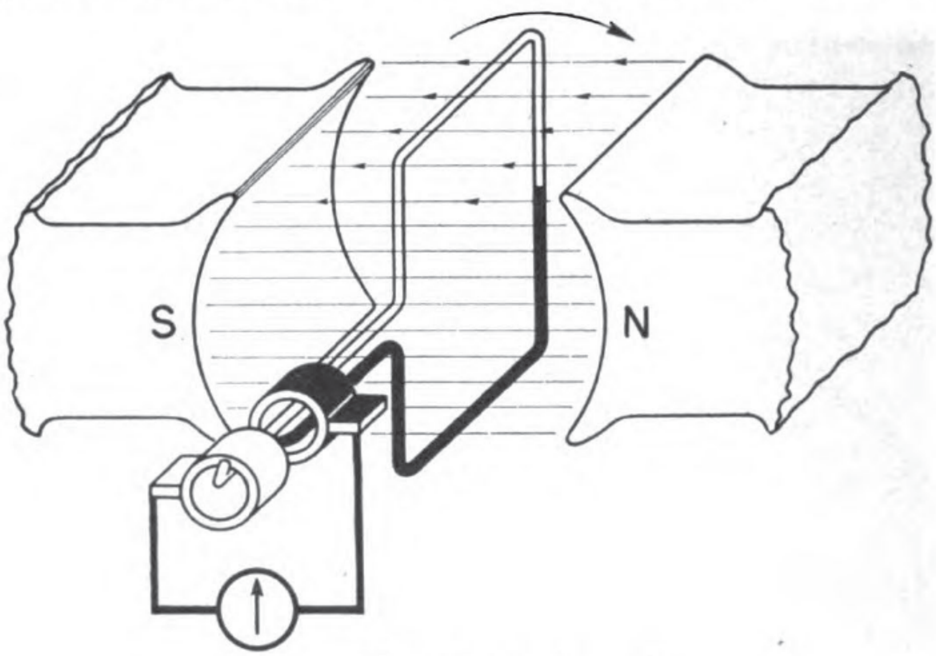


Figure 126.—Rotating loop—3.

been reversed in each part of the loop. Compare with figure 125.

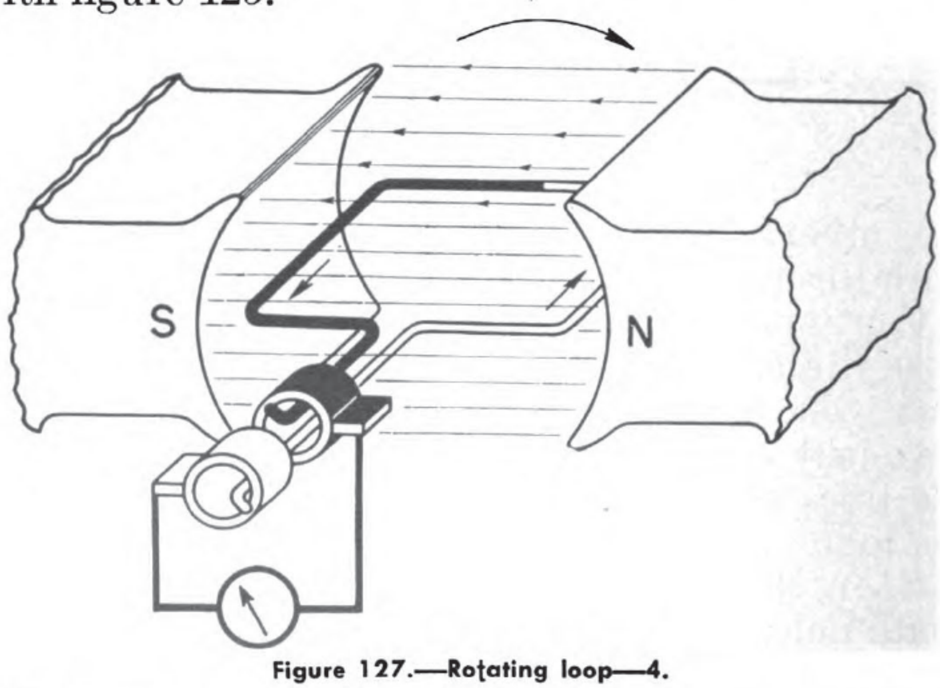


Figure 127.—Rotating loop—4.

THE EMF IN THE LOOP AS A WHOLE WILL REVERSE EACH TIME THE MOTION OF THE CONDUCTOR IS RE-

VERSED WITH RESPECT TO THE MAGNETIC FIELD and what is known as an ALTERNATING emf is generated in a loop of wire rotating in a magnetic field. You have a graph of an alternating emf in figure 128.

When you have the loop in position 1, observe once more that no lines of force are cut. Then

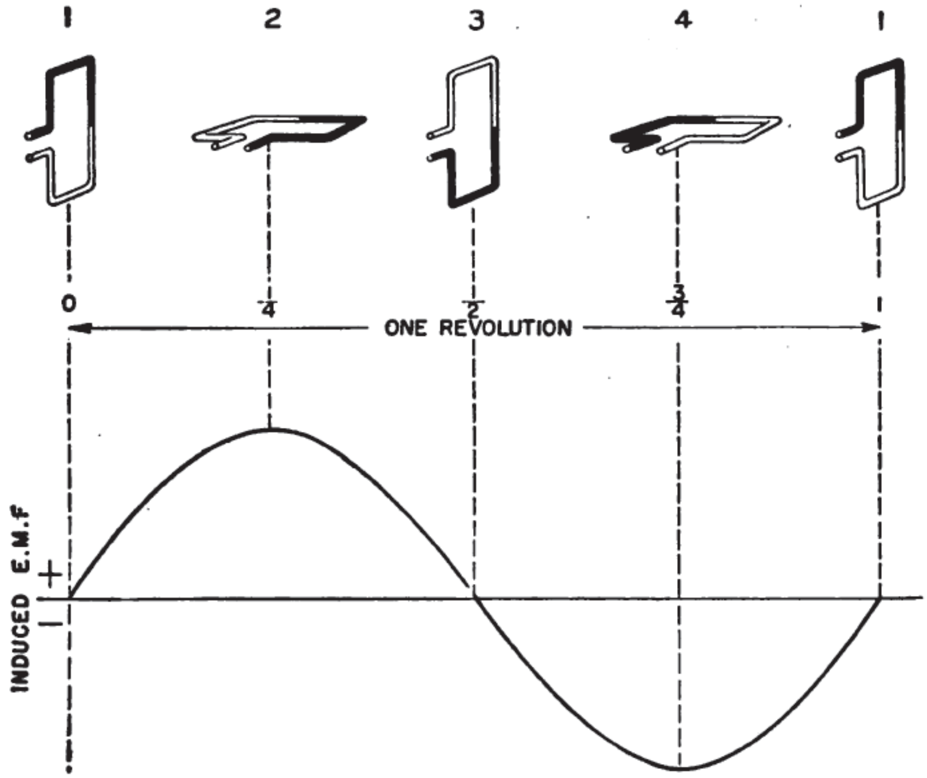


Figure 128.—Alternating emf.

the induced emf is zero. As you rotate the loop at constant speed, it begins to cut magnetic flux and an emf is generated.

When you get the loop into position 2, lines of force are being cut at a maximum rate and the induced emf is at a maximum, or PEAK VALUE.

The loop continues to rotate, the induced emf decreases in value, and again sinks to zero at position 3, where the loop is traveling parallel to—and NOT cutting—lines of force.

The induced emf surges up to a second PEAK VALUE at position 4. But the loop is cutting lines of force in a direction opposite to that in position 2. Hence the induced emf on each side of the loop is reversed in direction.

Complete the rotation of the loop, and you have it back to position 1, with the induced emf being zero.

The emf generated in a single loop reaches a peak value TWICE in a complete rotation.

TERMINAL VOLTAGE

When applied to the external circuit, the emf is called the TERMINAL VOLTAGE of the generator. By an amount equal to the *IR* drop in the loop, or armature, the terminal voltage is less than the induced emf.

CYCLES AND FREQUENCY

In a loop making one complete rotation, the induced emf—RISING FROM ZERO TO A MAXIMUM AND FALLING BACK TO ZERO, REVERSING ITS DIRECTION, AND AGAIN RISING FROM ZERO TO A MAXIMUM AND FALLING TO ZERO—is said to go through one CYCLE.

The FREQUENCY of an alternating emf is the NUMBER OF CYCLES PER SECOND. The faster the rotation of the loop, the higher the frequency. The frequency may also be increased by using more than two magnetic poles.

The FREQUENCY of an induced emf VARIES DIRECTLY WITH the SPEED of rotation, and the NUMBER OF MAGNETIC POLES which the conductor must pass to complete one rotation.

FORMULA—

$$f=p\left(\frac{v}{60}\right)$$

WHEN—

f=frequency of induced emf and current in cycles per second.

p=pairs of magnetic poles that the coil must pass.

v=speed of rotation (in revolutions per minute, or rpm).

$\frac{v}{60}$=number of revolutions (rotations) per second.

FOR INSTANCE—

If you have a 2-pole generator rotating at 3,600 rpm, what is the frequency of the induced current?

$$f=p\left(\frac{v}{60}\right)$$

$$=(1)\left(\frac{3,600}{60}\right)$$

$$=60 \text{ cycles per second}$$

This frequency is spoken of as "60 cycles."

ALTERNATOR

The alternating-current generator is also known simply as an ALTERNATOR. Alternators in practical use have electromagnets instead of permanent magnets. The winding of such an electromagnet is known as the FIELD WINDING. See figure 129. Because the polarity of the magnetic fields must remain unchanged, you must supply DIRECT CURRENT—that is, current whose direction does not change. This field current, or EXCITING CURRENT as it is called, is sent in from a source outside the alternating current generator. The source depends upon the construction and use of the alternator.

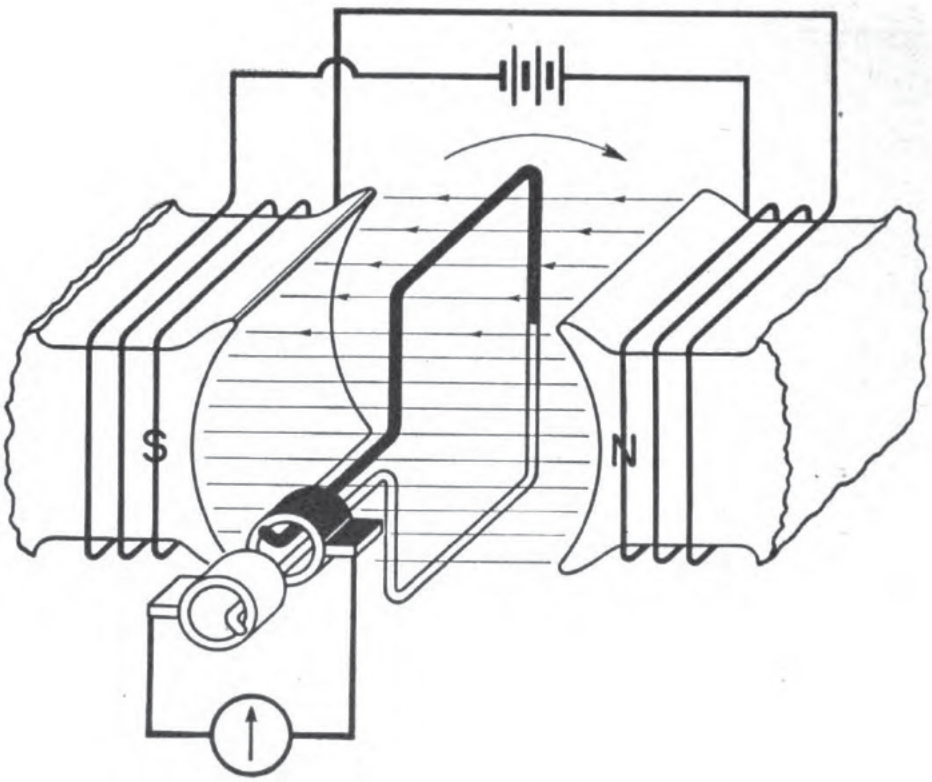


Figure 129.—Simple alternator.

ROTOR AND STATOR

You call the rotating part of the alternator the ROTOR, and the stationary part the STATOR. You don't care whether the conductor moves and cuts the magnetic lines of force or whether the magnetic lines of force move so that they are cut by the conductor. Either way, you win. Emf is induced whenever lines of force are cut by a conductor, no matter how they are cut. In alternators, usually the FIELD ROTATES. But rotating armatures may be used.

In the generator, the conductor coils which cut the magnetic lines of force make up the armature, whether rotor or stator.

DIRECT CURRENT GENERATORS

By a simple device, an alternating current emf can be turned into a direct current emf at the

terminals of a generator. This device is a split ring called a COMMUTATOR. Each half of the ring is termed a COMMUTATOR SEGMENT.

Look at figure 130, which shows a loop connected to a SPLIT ring instead of SLIP rings. Note that the ring has been cut at two opposite places, and that each end of the loop is connected to a segment. Because the armature is to rotate, you must have some form of sliding contacts to conduct current to the external circuit. These contacts are provided by two brushes placed so as to

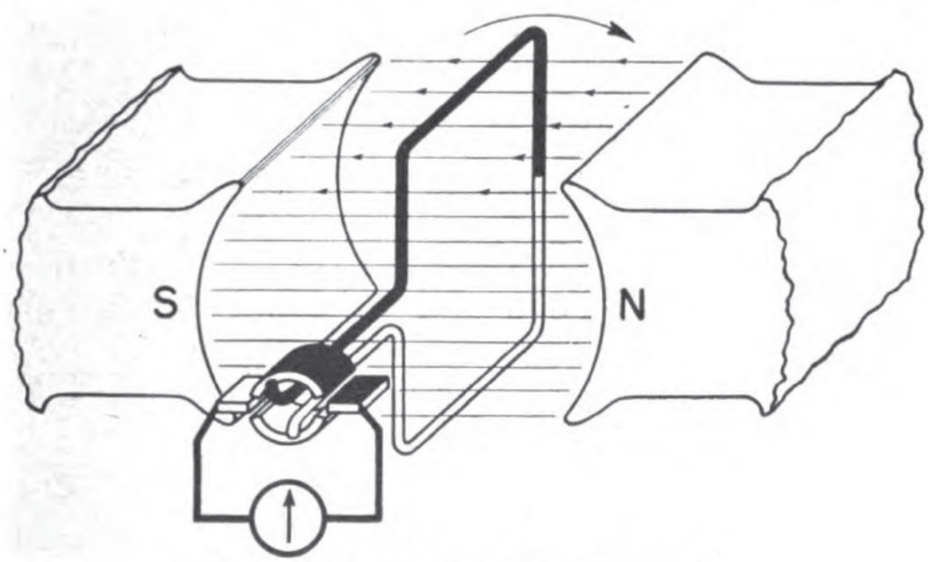


Figure 130.—Rotating loop—position 1.

press against opposite segments of the commutator. The external circuit is connected to these brushes.

Suppose you have a loop moving as you see in figure 130. Is any emf being induced in it? Nay, not one jot nor one tittle. The sides of the loop are moving parallel to the lines of force and obviously do not cut them.

Now rotate the loop in a CLOCKWISE direction as you see in figure 131.

The black part of the conductor goes downward across the face of the north pole. The white

part goes upward across the face of the south pole. Apply the right-hand catch rule—TWICE,

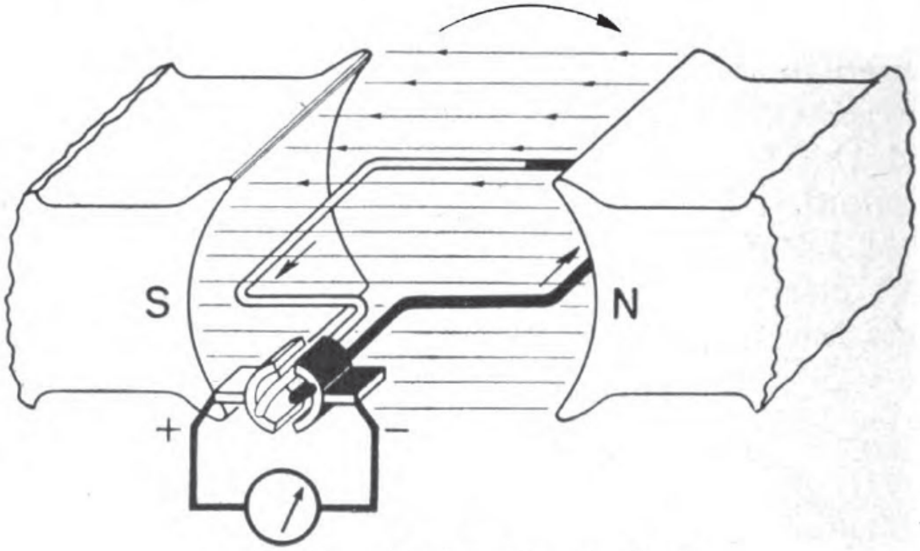


Figure 131.—Rotating loop—position 2.

of course—and you check with the diagram on the directions of the currents induced in each part of the loop.

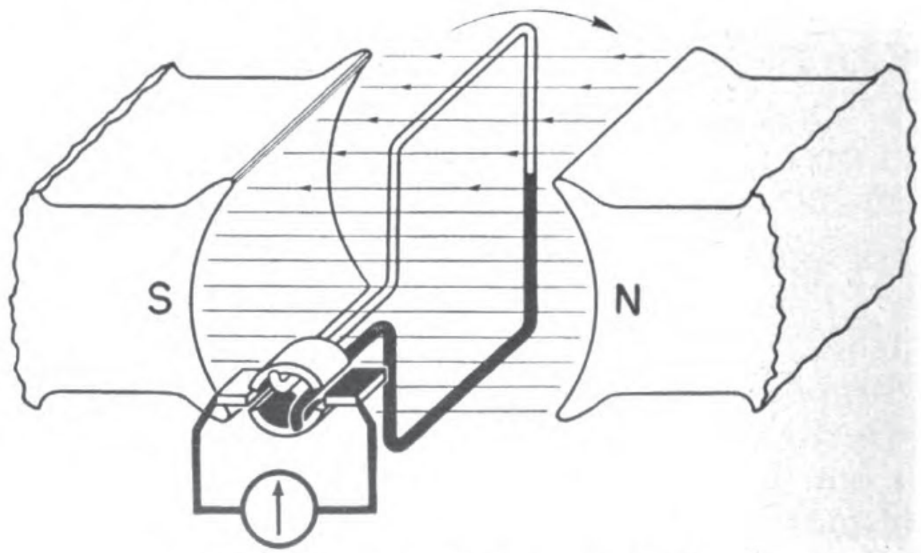


Figure 132.—Rotating loop—position 3.

Observe carefully that the current LEAVES by way of the WHITE commutator segment. So this segment and the brush pressing against it are

POSITIVE. The current RETURNS to the BLACK segment through the black brushes which therefore are NEGATIVE. Does this marking of positive and negative terminals differ from the marking of battery terminals? No. The brush, or terminal, from which the current EMERGES is the POSITIVE terminal.

Keep turning the loop until it again reaches a vertical position, as you see in figure 132. Again no emf is present in the loop. The sides are

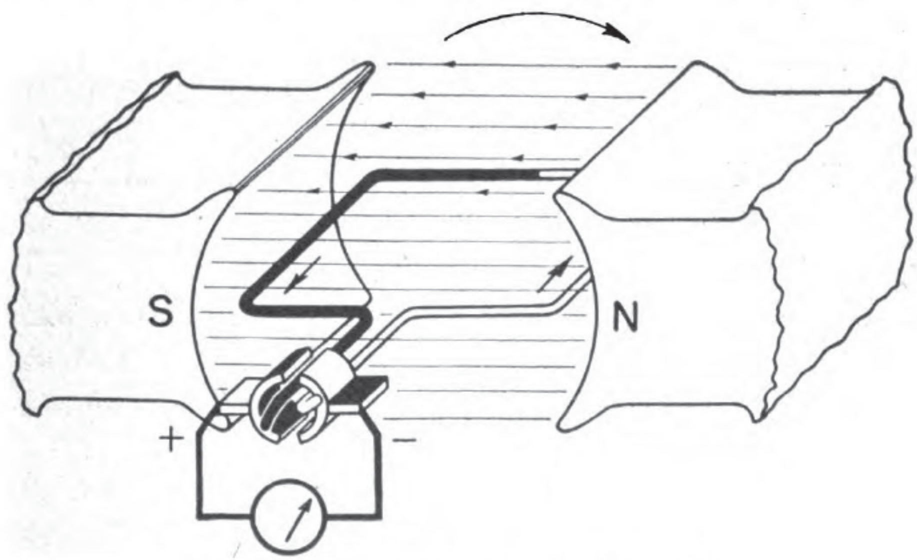


Figure 133.—Rotating loop—position 4.

moving parallel to the lines of force. The brushes, FOR THE MOMENT, therefore are neither positive nor negative.

In figure 133, you have the black part of the conductor moving upward across the face of the south pole and the white part moving downward across the face of the north pole. The current is thus REVERSED in the black side of the loop, and LEAVES by way of the BLACK COMMUTATOR SEGMENT. But, in this position, it is pressing against the

WHITE brush. So the WHITE BRUSH is again POSITIVE.

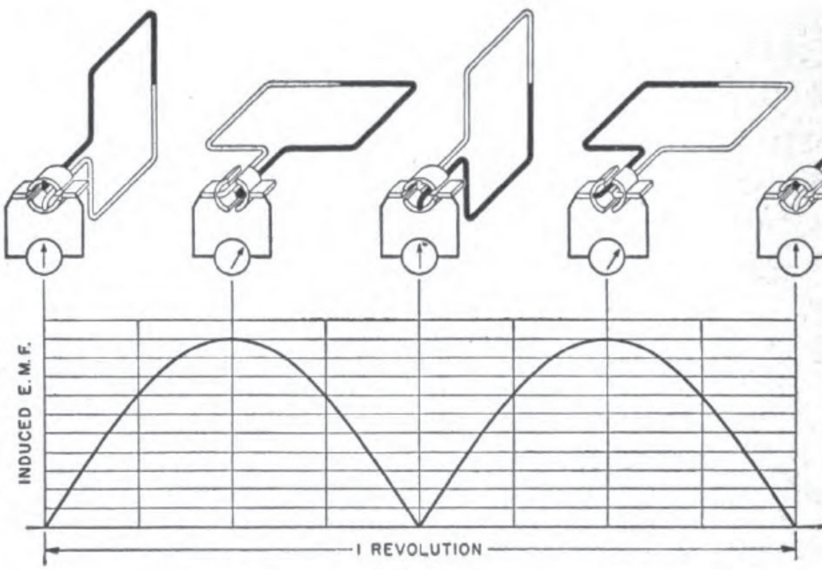


Figure 134—EMF from a single loop.

The white commutator segment is now NEGATIVE. But it, too, is pressing against a different brush, the BLACK brush, which therefore is STILL NEGATIVE.

During a complete rotation, a voltmeter connected to the brushes would show two deflections, BOTH in the same direction. See figure 134, which graphs the PULSATING, DIRECT CURRENT.

A generator with a single loop yields only a very low, markedly pulsating emf. You can develop a higher emf with less variation, or pulsation, by use of many loops. In figure 135, you have a graph of the emf variations in a two-loop, or double-loop, armature. Note that the voltage applied to the external circuit is NEVER zero. When the emf in one loop is zero, in the other loop the emf is maximum. There is less variation in voltage than when you have only a single loop. Yet the output still pulsates markedly. Add more loops, then the voltage out-

put and, therefore, the current in the external circuit, are SMOOTHER—that is, show less and less variation.

The number of coils added depends on the required output of the generator. For practical purposes, you can consider the output of a d-c generator as steady, or PURE d. c.

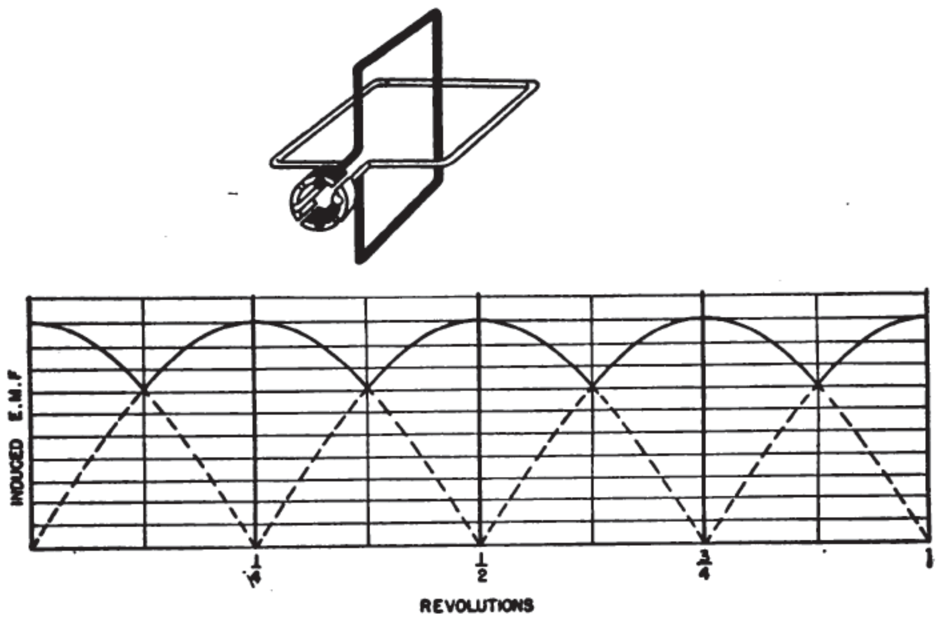


Figure 135.—EMF from double-loop armature.

Of course, as you observed in the case of the a-c generator, the voltage output depends upon the number of lines of force cut per second. Hence the d-c generator, like the a-c generator, uses an electromagnetic field.

EXCITING THE FIELD

In (*A*) of figure 136 you have a single-loop armature with an electromagnetic field whose current is supplied by a battery. You call this field a SEPARATELY EXCITED FIELD. But this type of field is used only for scientific research. The voltage obtained from the generator is d. c. Hence a part of the output current can be diverted to the field

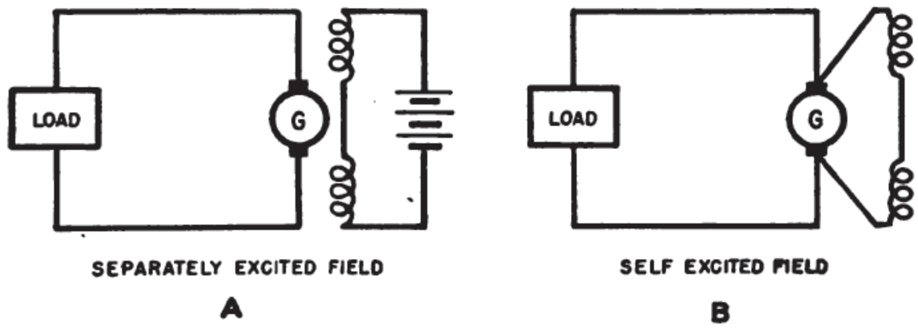


Figure 136.—Field windings.

windings to excite the field. The generator is the SELF-EXCITED, as in (*B*) of figure 136.

RESIDUAL MAGNETISM

When a self-excited d-c generator comes to a stop, no voltage is present at the brushes, the field current drops to zero, and the electromagnetic field loses ALMOST all of its excitation. The electromagnet retains a small amount of magnetism, known as RESIDUAL MAGNETISM. This weak field makes it possible to start the generator again. Lines of force are there, ready to be cut by the conductor.

TYPES OF GENERATORS

There are three types of generators—SHUNT, SERIES, and COMPOUND generators. The names indicate how the field circuit is connected with respect to the armature circuit.

In (*A*) of figure 137, you see the connections used for the SHUNT generator. The field windings are in series. But the entire field is parallel or shunted across the armature circuit. The diagram indicates the paths taken by the field and armature currents. This type of generator is used in Naval aircraft almost exclusively.

In (*B*) of figure 137, you see the connections used in the SERIES generator. The field windings

in this generator must be able to take the entire output current. The individual fields are in parallel to give more paths for current flow. But the field winding as a whole is in series with the armature circuit. You use this type generator for heavy and variable loads.

The COMPOUND generator in (*C*) of figure 137 uses both series and shunt windings. In the case of the shunt generator, the terminal voltage of the generator drops when the load increases, because the increase in current causes an increase in the *IR* drop inside the armature. The compound

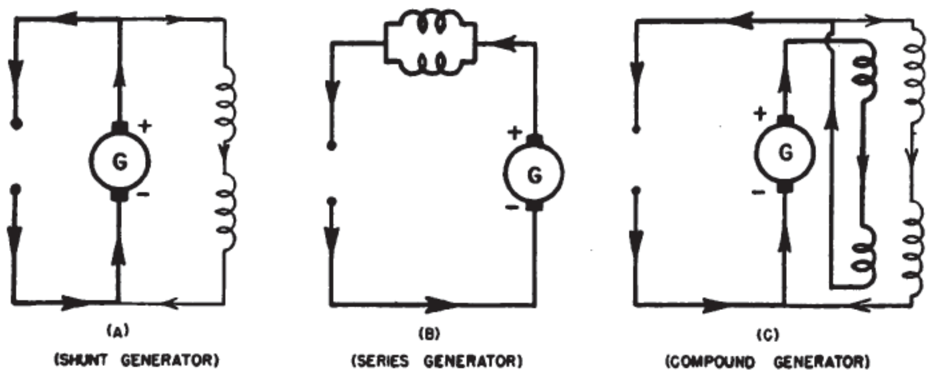


Figure 137.—Types of generators.

generator compensates for this with an additional winding placed on the field poles and connected in series with the armature. The winding is arranged so that it aids the shunt field. The increase in the magnetic field tends to keep the voltage constant. The series winding is of larger wire than the shunt winding so that the series winding can carry full load current. The series winding also has comparatively few turns.

AIRCRAFT ELECTRICAL SYSTEM

In most aircraft, the electrical system consists of an engine-driven generator, a voltage regulator, a cut-out relay, and a storage battery. The generator supplies the load current to the system.

Part of this load current is charging current to the battery. Inasmuch as the engine speed changes during flight operation, the speed of rotation of the generator also varies. This results in an uneven voltage output from the generator.

Now it is easy to see what would happen if this uneven voltage output were allowed to reach the rest of the system. All electrical devices are designed to operate at a definite value of current.

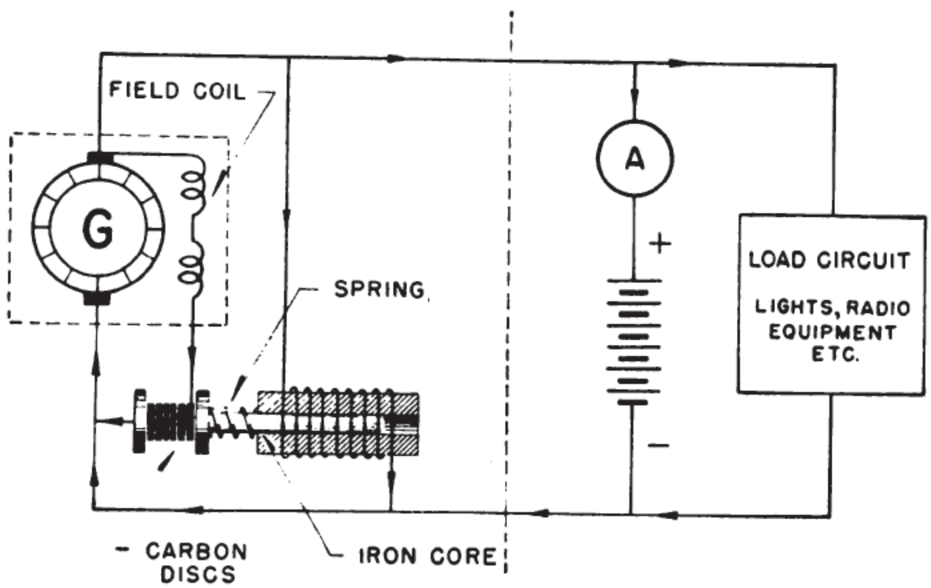


Figure 138.—Voltage regulator circuit.

The correct current will be obtained only if the voltage applied to the device is kept constant. Thus, if the voltage is too high, the devices are subject to damage. In the case of lights, a burn-out occurs immediately. If applied voltage is low, the devices receive insufficient current. If the applied voltage is TOO low, the devices will not operate at all. The voltage regulator puts a CEILING on the amount of voltage that can be applied to the electrical system.

In figure 138, you see a diagram of a voltage regulator circuit. This circuit consists of a carbon pile rheostat, or variable resistor, inserted

in the field circuit of the generator. Field current of the generator must flow through a series of carbon wafers held together by a spring. The resistance from one end of this series of wafers to the other end is determined by the tension of the spring. When the spring tension is released, the wafers move apart. In this position, the wafers only touch each other at certain points and the resistance is increased. Conversely, when the spring tension is high, the wafers are pressed together firmly and the over-all resistance decreases. The tension of the spring is controlled by a solenoid connected across the generator terminals.

If the voltage of the generator increases above the prescribed limit, the current in the solenoid created by this voltage also increases. The solenoid then attracts the iron core which eases the tension on the carbon pile spring. The increase in resistance which results cuts down the field current and the magnetic flux produced by this field current. Because the generator armature has less flux to cut, the induced voltage of the generator decreases. Thus the generator voltage cannot exceed a voltage determined by the spring tension. As you might guess, the carbon pile regulator in figure 138 is a simplified version of the actual regulator.

REVERSE CURRENT CUT-OUT RELAY

In aircraft, the voltage regulator prevents the generator from exceeding the voltage required for operation of the electrical devices in the load. But it cannot prevent the voltage of the generator from falling if the engine speed is insufficient. Furthermore, when the engine is stopped the generator has no voltage whatsoever. At such times, the battery would discharge into the gen-

erator. Thus current would be wasted. It might also cause serious damage to the generator armature. To prevent this effect, a cut-out relay is placed in the electrical system.

In figure 139, you see the action of a typical reverse current cut-out relay. Normally, the contact points of the cut-out relay are held open by

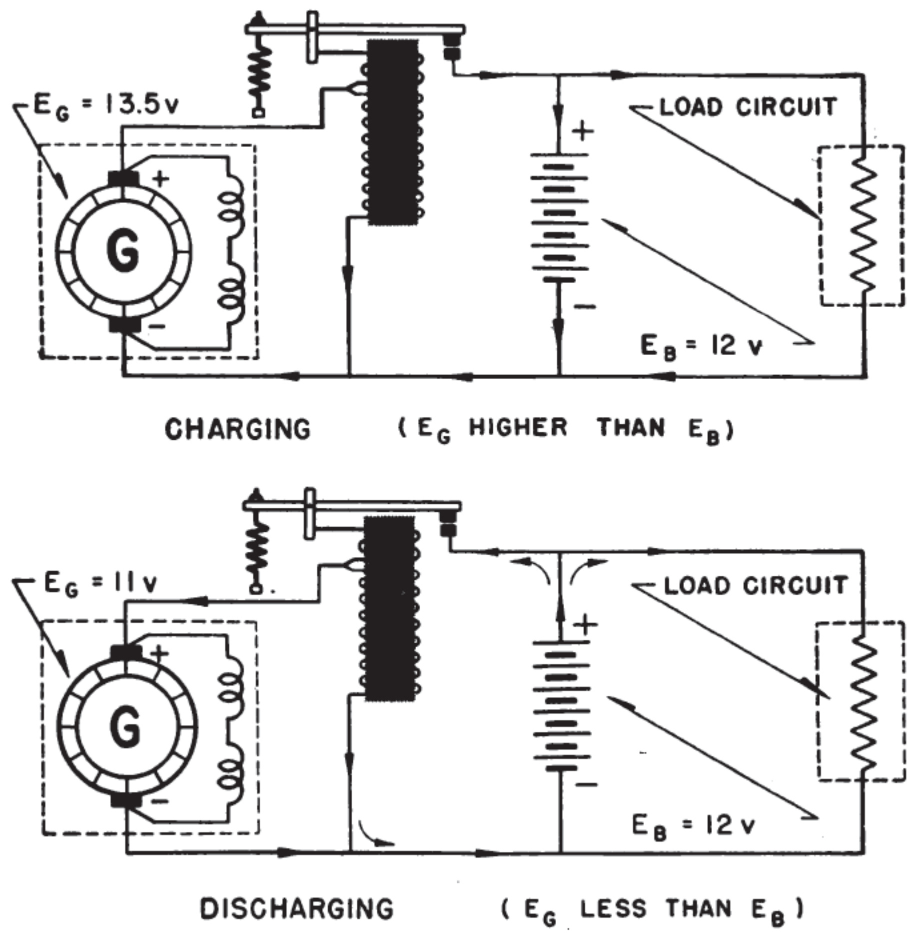


Figure 139.—Reverse current cut-out relay.

a spring. Under this condition, the generator is disconnected from the line. As the engine begins to rotate, the generator voltage increases and sends a current through the shunt coil of the relay. The shunt coil is always across the generator terminals. The current in this shunt coil is proportional to the generator voltage. The ten-

sion of the contact spring is so adjusted that the relay contacts close when the generator voltage slightly exceeds the battery voltage.

The action of closing the contact points connects the generator to the line. Current from the generator continues to flow through the shunt coil. But it also passes through the series coil, the contact points and the load circuit. The generator now can supply the load circuit and the charging current for the battery.

Note that the direction of current in both the shunt and series coils is such that the coils assist

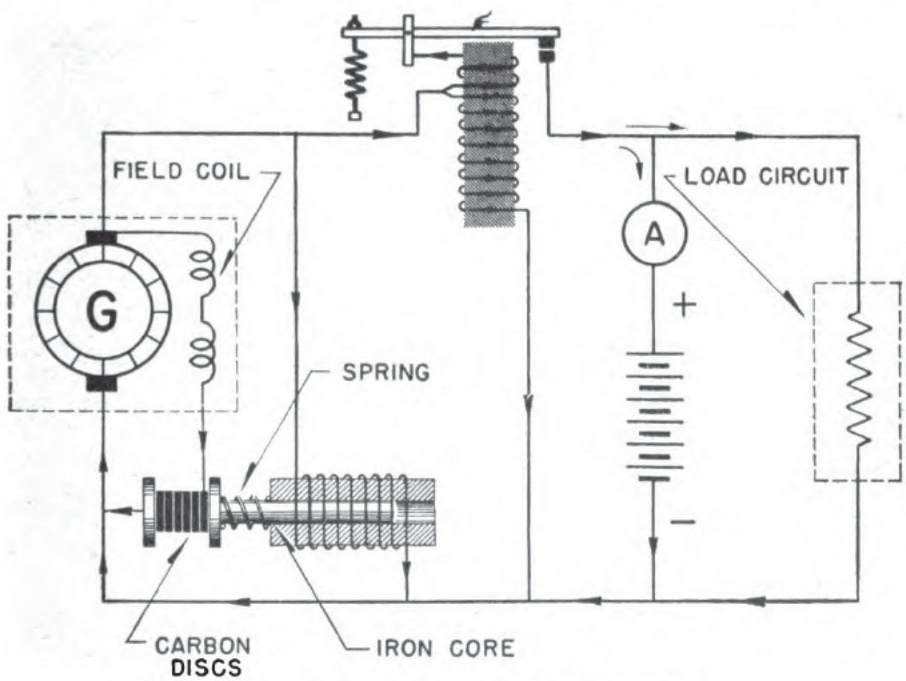


Figure 140.—Aircraft electrical system.

each other in magnetizing the core. If the load current or the charging current increases, the relay contact points are held more firmly together. Thus the relay does not regulate the charging rate, or affect the load current in any way.

When the engine speed decreases, the generator speed also decreases and the generator voltage

drops. When the point is reached where the generator voltage is less than the battery voltage, the battery momentarily will discharge through the generator. This discharge-current passes through the series coil in an opposite direction. Current direction in the shunt coil continues in the original direction. The series coil now opposes the shunt coil and cancels the magnetism of the core. This action permits the spring to separate the contacts and disconnect the generator from the circuit.

An examination of figure 140 will show you how the generator, the voltage regulator, the cut-out relay, and the battery are connected in an aircraft electrical system.

CHAPTER 13

DIRECT CURRENT MOTORS

USES

Electric motors are used in all types of aircraft. Starters, turrets, bomb hoists, landing gears and many other devices all use electric motors. The dynamotor, a power supply for radio receivers, is really a combined electric motor-generator encased in one housing. In general, electric motors convert electrical energy into mechanical energy.

There are both a-c and d-c motors. This book discusses d-c motors only.

ST. LOUIS TYPE MOTOR

Did you ever hear this before?—Like magnetic poles repel each other, and unlike poles attract each other. Motors make use of this principle to produce rotation. The St. Louis type motor, such as you see in figure 141, is not a commercial type

motor. But a study of it will help you understand the principles involved in all motors.

The St. Louis type motor has two electromagnets. One is stationary. The other is mounted on a shaft and can rotate. Battery current flowing in the winding gives the electromagnets the indicated magnetic polarity. To make rotation possible, the connections to the rotating member

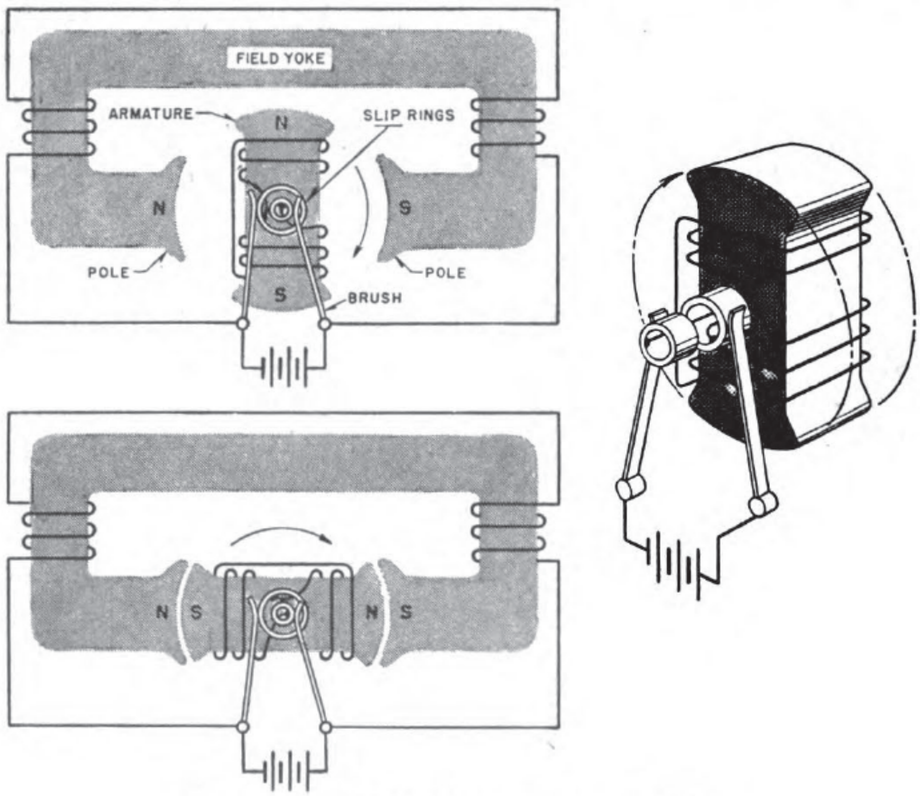


Figure 141.—St. Louis type motor—slip ring.

(armature) must be in the form of a sliding contact. Both ends of the armature winding terminate on slip rings which are attached to the armature and rotate with it. The current passes to the coil by brushes that press against the slip rings. Thus, current can flow to the armature during its movement. The stationary electromagnet is known as the FIELD MAGNET. The poles of the field magnet are known as the FIELD POLES.

Part of the battery current flows through the field windings to supply the field current.

When current flows, FOUR magnetic forces act in the circuit. The north pole of the armature is

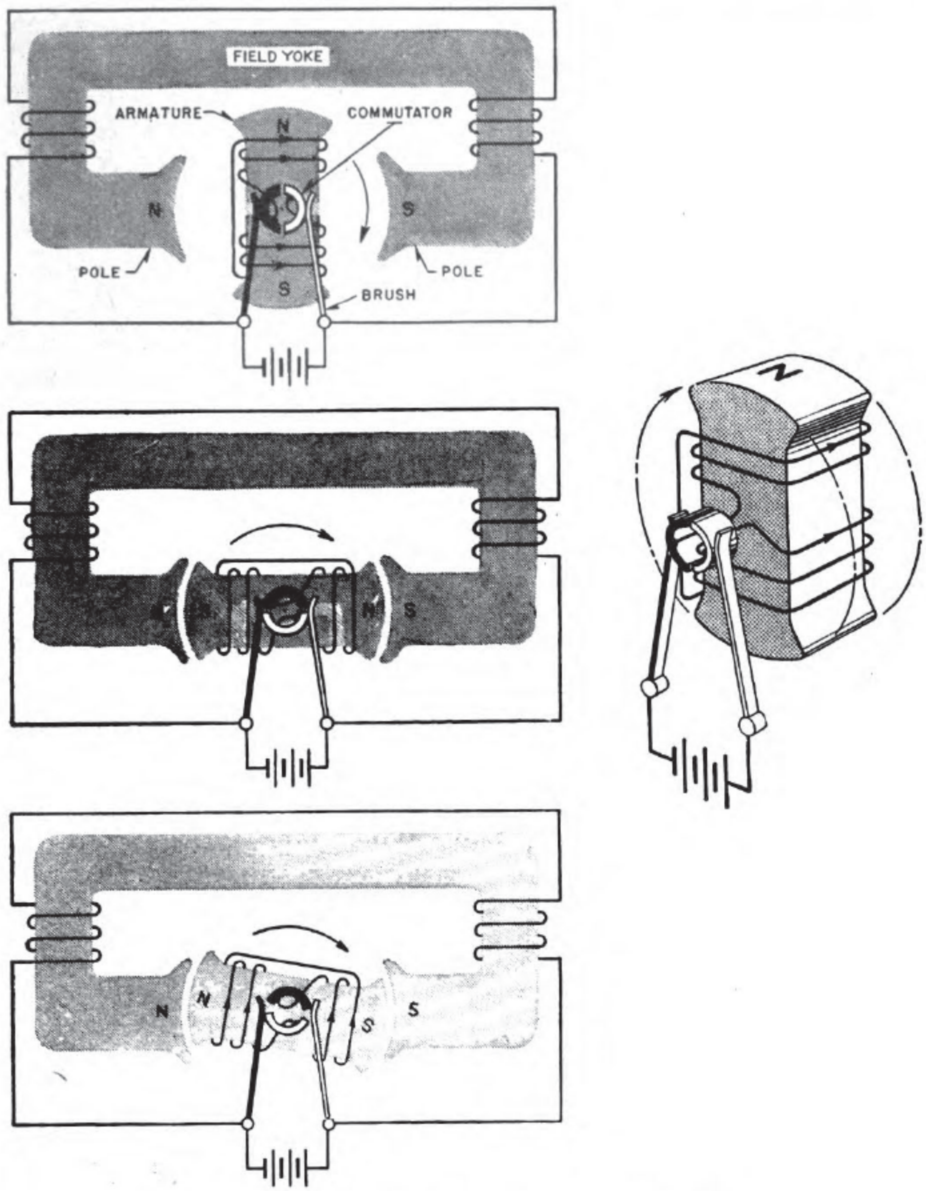


Figure 142.—St. Louis type motor—split ring.

repelled by the north field pole, and is attracted by the south field pole. The south pole of the armature is repelled by the south field pole, and attracted by the north field pole. All four forces

tend to produce rotation in a clockwise direction.

This arrangement produces rotation for only one-half of a complete turn, or revolution. Then unlike poles are opposite each other, and as close to one another as possible, so the armature locks itself in this position. Although this arrangement is unsuitable for a motor where rotation must be continuous, it does have a direct application to the internal construction of d-c voltmeters and ammeters.

THE COMMUTATOR

If the armature is to rotate continuously, some means must be provided for reversing the magnetic polarity of the armature whenever its poles are directly in line with the field poles. This is the function of a COMMUTATOR.

The armature in figure 142 has a SPLIT-RING-COMMUTATOR—a ring split into two segments, as you already know. The segments are insulated from each other and mounted on the armature for rotation with it. Current is led into the armature winding in much the same way as it is with slip rings. But a means is now provided to reverse the armature current automatically.

When the armature is in clockwise rotation, the action is similar to that for operation with slip-rings. However, when the armature reaches the horizontal position, the stationary brushes rest on the split portion of the commutator. The momentum of the armature then carries it past this position. Whenever this occurs, each segment of the commutator loses contact with one brush and contacts the other. This reverses the current in the armature. Therefore, the MAGNETIC POLARITY of the armature is also reversed. Each pole of the armature is now repelled by the field pole nearest it and rotation continues. The armature

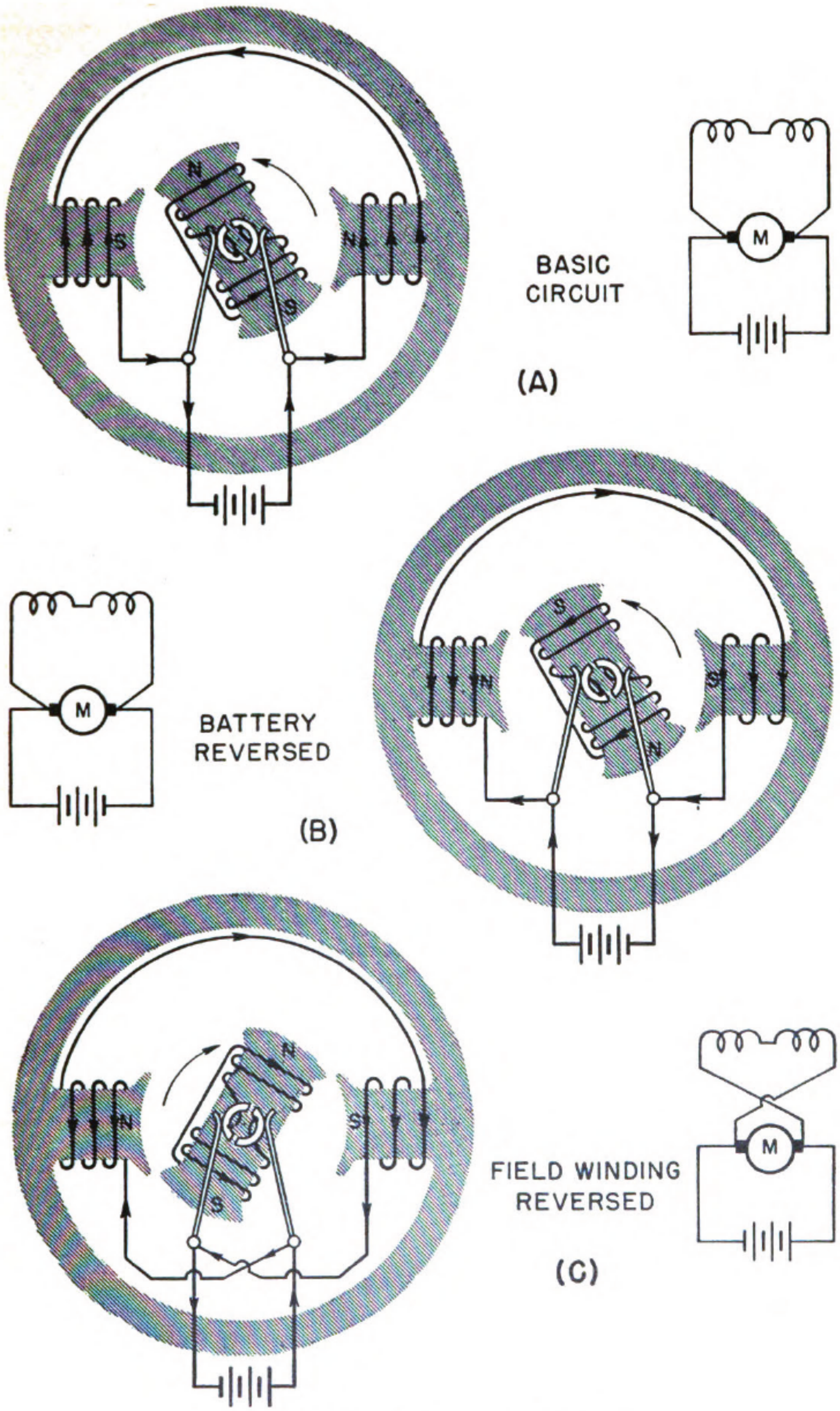


Figure 143.—Direction of rotation.

then makes another one-half revolution and reversal again takes place. The effect of these reversals is to produce continuous rotation of the armature.

DIRECTION OF ROTATION

It is often necessary to reverse the direction of a motor. You might think you could do this by reversing the battery connection. But such a reversal has no effect whatever on the direction of rotation. In (*A*) and (*B*) of figure 143, you see the magnetic effect that results from reversal of the battery connections. The magnetic polarity of both field and armature is reversed and rotation remains the same. How can you reverse the rotation? There are two ways.

Reverse the current direction in the armature only.

Reverse the current direction in the field only.

The second method is the easier. Simply reverse the field leads at their connection points on the brushes. You see the magnetic conditions that result from this change in (*C*) of figure 143.

COMMERCIAL ARMATURES

The armatures in commercial motors are different in construction from the one in the St. Louis type motor. Before studying these armatures in detail, it will be necessary to review certain principles of magnetism and electromagnetism.

Refer to figure 88 and note the magnetic field of two permanent magnets. Lines of force in the same direction crowd each other apart and produce repulsion. If only one of the magnets is stationary, the other will move away from it.

A current-carrying conductor has a magnetic field around it. If you place it in another mag-

netic field, the two magnetic fields react on each other. In (*A*) of figure 144, you see the magnetic field of the conductor (conductor flux) in relation to the magnetic field of the motor. Above the conductor, the field flux and conductor flux are in the same direction below the conductor. Re-

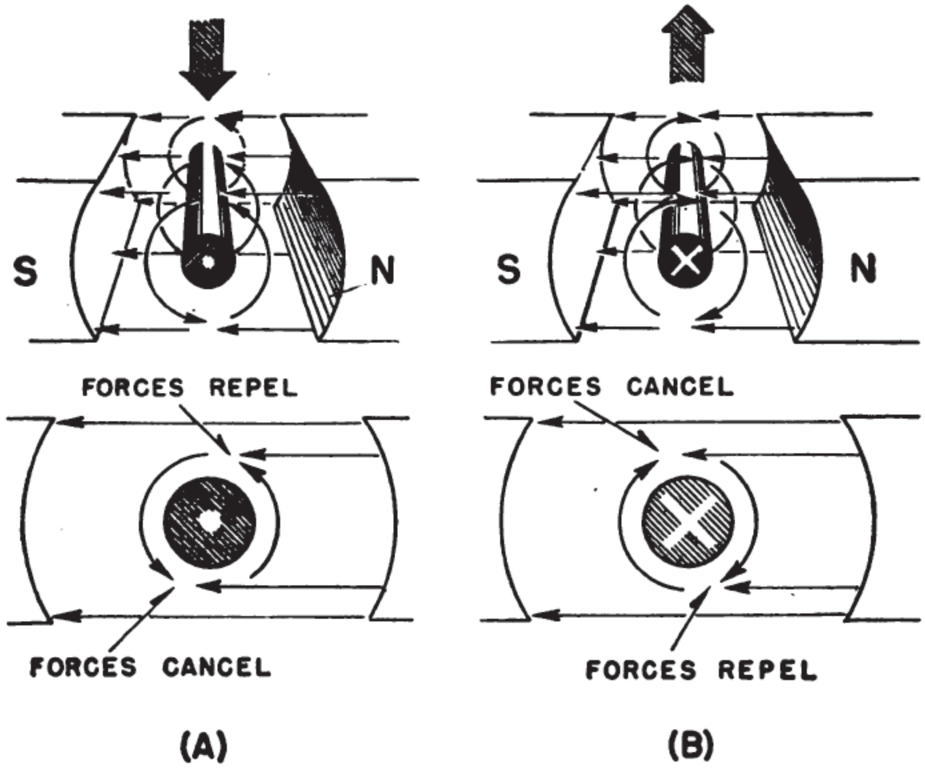


Figure 144.—Motor action.

pulsion at this point causes the conductor to move upward.

Now you should understand the RULE FOR MOTOR ACTION—

> A CONDUCTOR CARRYING CURRENT IN A MAGNETIC FIELD MOVES AWAY FROM THE POINT WHERE FIELD FLUX AND CONDUCTOR FLUX ARE IN THE SAME DIRECTION.

In figure 145, you have a loop of wire placed between two permanent magnets. Current is led to the loop through a split ring commutator. The current flows in opposite directions on each side

of the loop. Because of this current flow, a magnetic field exists around and along each side of

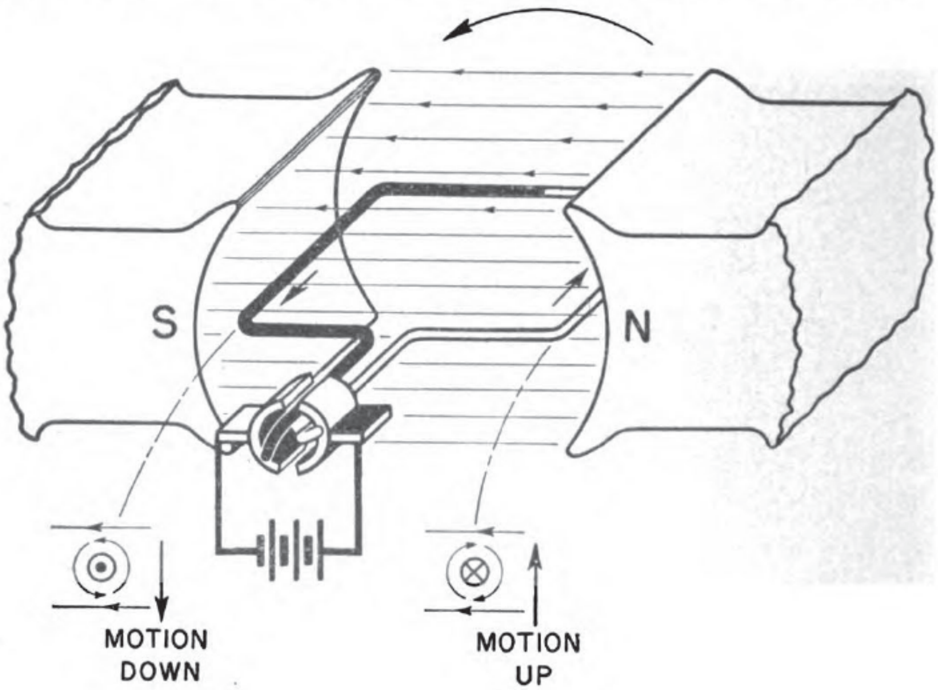


Figure 145.—Single loop armature—1.

the loop. On the right-hand side of the loop, the conductor flux and field flux are in the same direc-

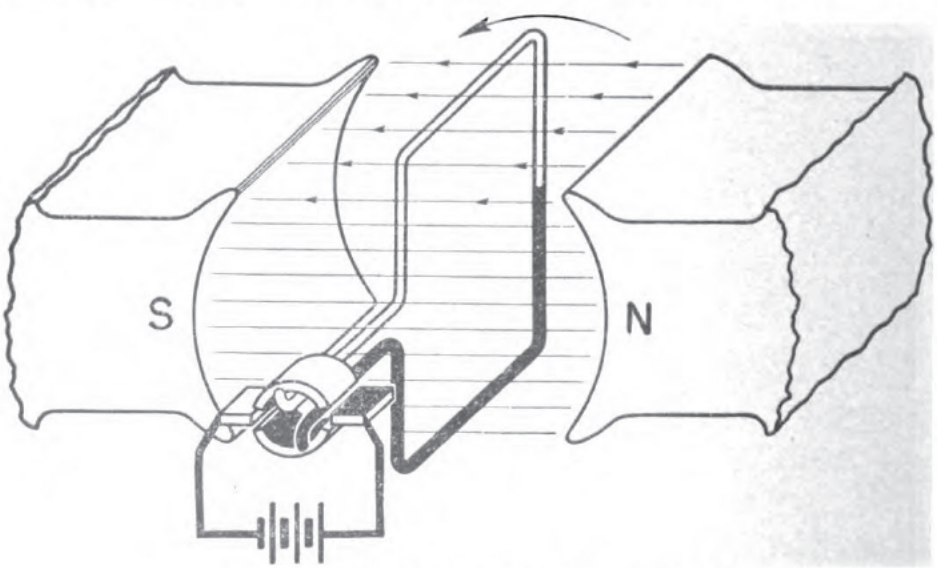


Figure 146.—Single loop armature—2.

tion on the bottom. The crowding of flux at this point will force that side of the loop upward. On

the left hand side of the loop, the magnetic conditions are reversed and the loop on this side will be forced downward. The result is the rotation of the loop in a counter-clockwise direction.

In figure 146, the loop has reached a vertical position and the brushes rest on the insulated position between the segments. No current flows in the loop and no force is present to produce rotation. The loop, however, has gained momentum from rotation in the preceding one-quarter revolution and passes this neutral position.

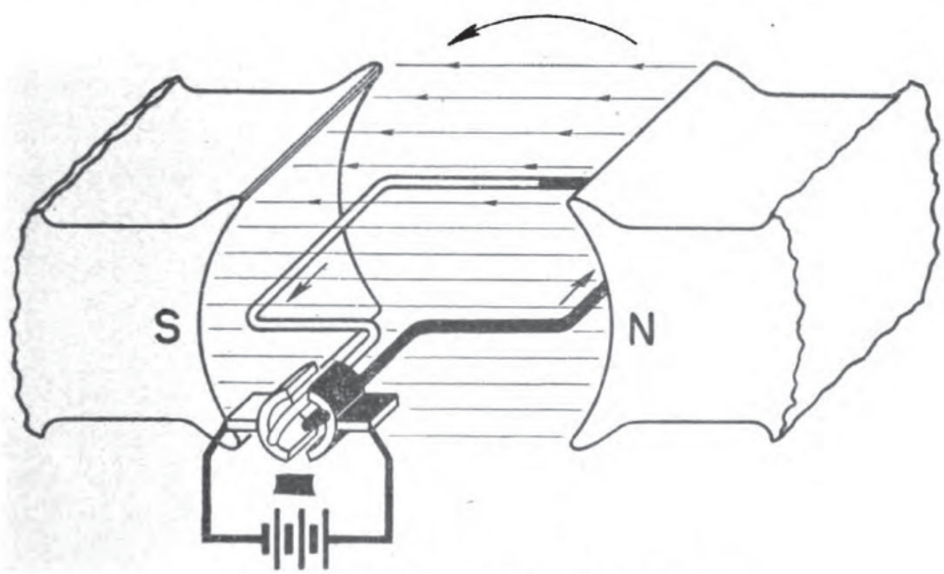


Figure 147.—Single loop armature—3.

In figure 147, the commutator segments have interchanged position on the brushes, and current has reversed in the loop. So you have a reversal of flux direction on both black and white sections of the loop. And, as each side of the loop passes a particular pole, the current in the conductor is kept in the same direction with respect to the poles. An application of the rule for motor action will show that the magnetic force on each side of the loop is such that the rotation is maintained in the same direction.

The torque, or TURNING FORCE, developed by this simple loop armature depends upon the strength of the magnetic field developed by the loop and the field poles. For this reason, electromagnetic fields are used in all types of motors.

In figure 148, you see diagrammed a single loop armature with an electromagnetic field. Current for this field is supplied by the battery. In this particular case, the field winding is in parallel with the armature. Hence the motor is a shunt, or parallel, motor, and closely resembles the St.

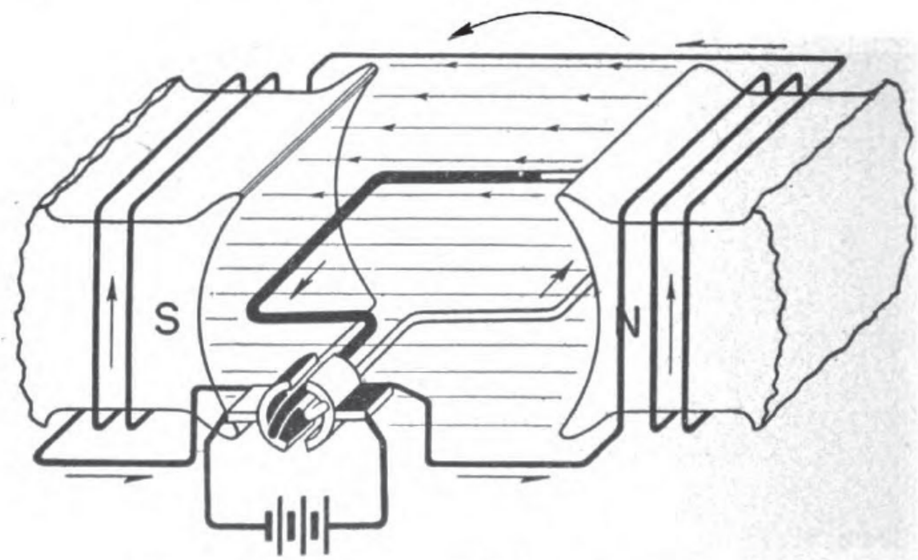


Figure 148.—Electromagnetic field—shunt connection.

Louis type motor. The magnetic conditions required to produce rotation in any particular direction are the same for each type. The direction of rotation can be reversed by interchanging the field connections at the brushes.

A single loop armature is of little use for a commercial motor. The torque, or mechanical TWIST force, applied to the motor shaft is both weak and pulsating, even with an electromagnetic field. Whenever the loop approaches its vertical position, the magnetic force acts to spread the loop apart and only part of the force is effective

in producing rotation. Whenever the loop passes the vertical position, most of the force is acting

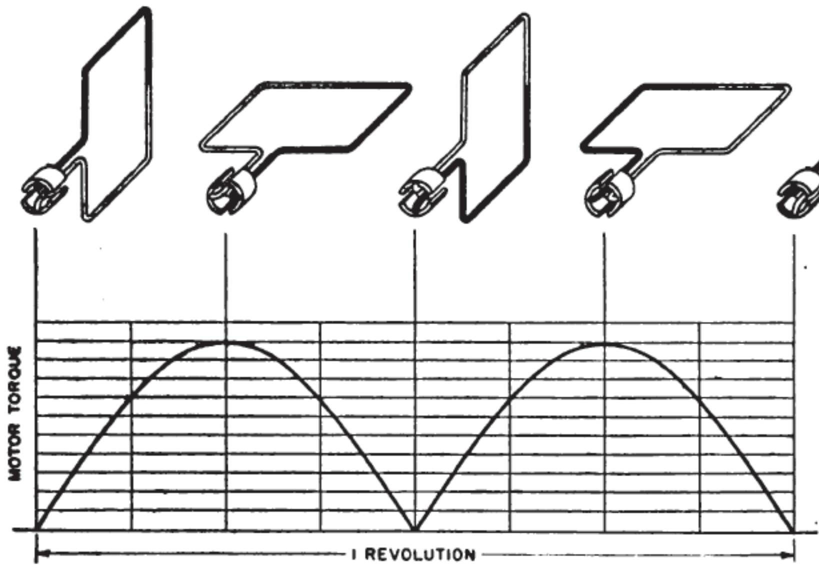


Figure 149.—Torque graph—single loop armature.

to compress the loop. The maximum turning force is developed when the loop is in a horizontal

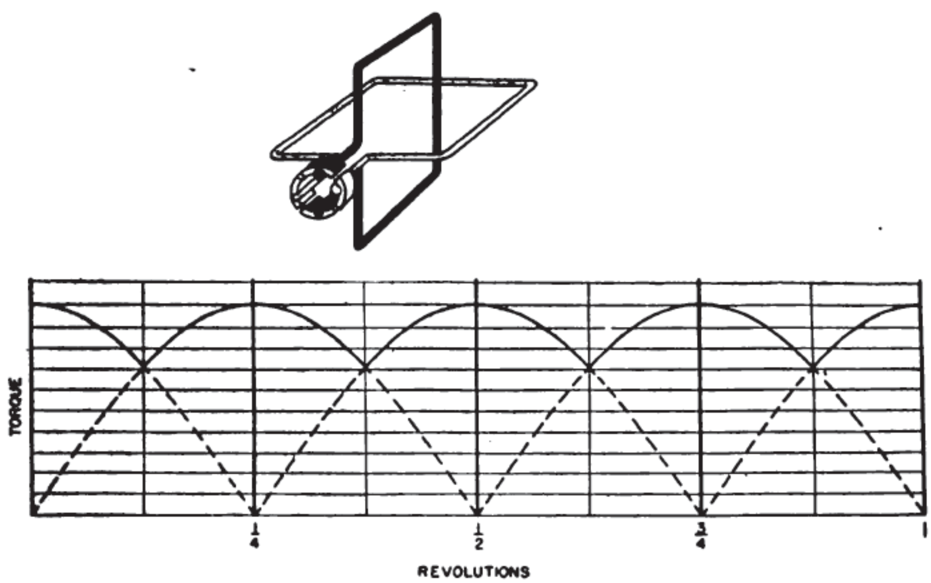


Figure 150.—Torque graph—double loop armature.

position. The minimum turning force is developed when the loop is in a vertical position.

The graph of motor torque for a single loop armature over a period of one complete revolution is shown in figure 149. But you don't want the pulsation.

By the trick of adding more loops to the armature, you SMOOTH OUT these pulsations and obtain a more uniform force. In figure 150, you can observe the torque curve that you get with a DOUBLE loop.

The difference between the maximum and minimum values is not as great as the single loop. But the torque is still pulsating.

In figure 151, you see the armature of a typical starter motor. The armature has MANY LOOPS of wire WITH ADDITIONAL SEGMENTS to reverse the

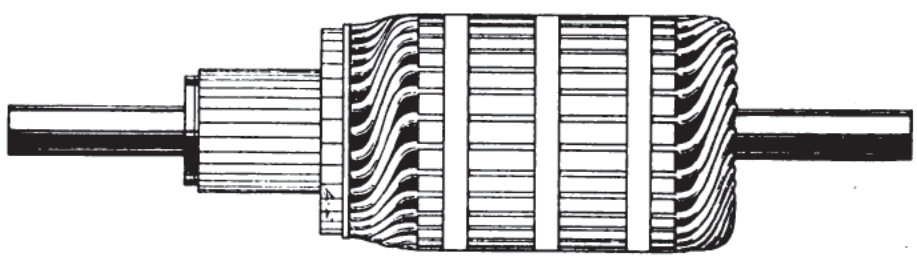


Figure 151.—Starter motor armature.

current in the loops AT THE PROPER TIME. The action produced may be compared to the addition of cylinders in the automobile or airplane engine. You obtain a greater torque and, more important, a more uniform torque.

COUNTER EMF

The armature of a motor rotates because of the magnetic reaction between armature and field. As the armature rotates, the conductors on it cut the magnetic lines of force in the field. Whenever magnetic flux is cut by a conductor an emf is induced in the conductor. So the armature develops what is known as COUNTER-EMF. This

counter-emf acts against the impressed voltage being used to drive current to the armature. The current that flows in the armature circuit is governed by the strength of these two opposing voltages.

In figure 152, you have a motor and lamp operating in a parallel circuit from a d-c voltage source. The lamp and motor both have the same voltage rating. An ammeter is connected in the circuit to indicate the amount of current flow to the motor. Now, when the switch is closed and voltage is applied to both lamp and motor, the current flow through each unit is along the path indicated by the arrows. After the motor has

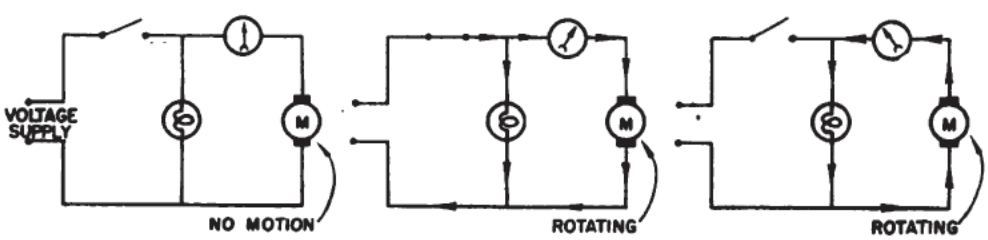


Figure 152.—Counter-EMF.

reached full speed, you can open the switch and the lamp will continue to burn for a while. It will grow dimmer as the motor speed falls. The instant the switch is opened, the ammeter deflection reverses. Therefore, the voltage forcing current through the lamp is in an opposite direction to the applied voltage.

When a motor is in operation at light load, the impressed voltage is slightly greater than the motor counter-emf. So current is forced into the armature by the DIFFERENCE VOLTAGE. When load is applied to a motor, the speed of the motor decreases, and the motor develops a lower counter-emf. The difference between impressed voltage and counter-emf becomes greater and more current flows through the armature to accommodate the

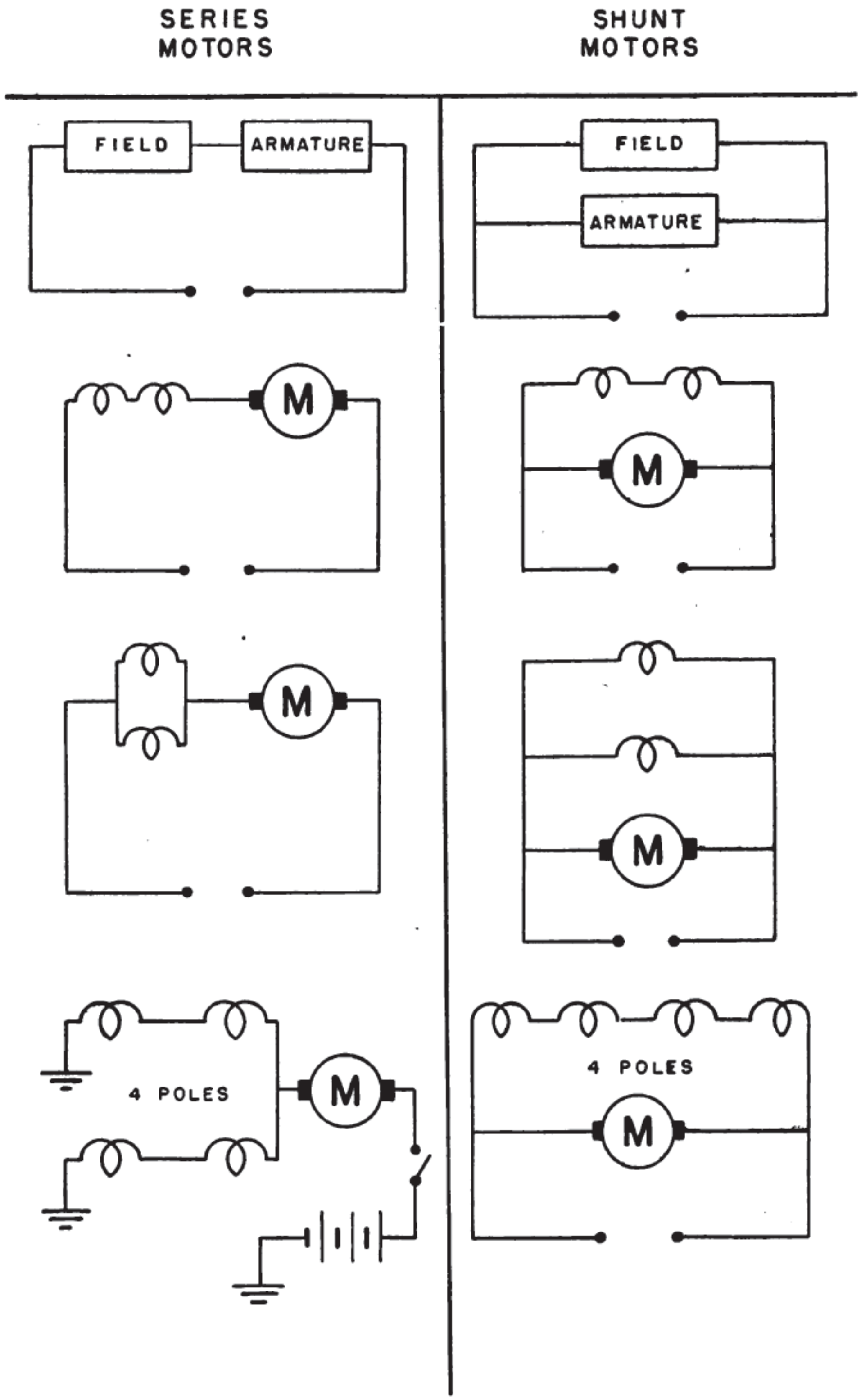


Figure 153.—Motor schematics.

additional load. Thus, a motor UNDER LOAD draws more current at LOW speed than at high speed.

At the instant of starting, the motor speed is zero, and no counter-emf is present. The FULL IMPRESSED VOLTAGE is effective in forcing current through the armature. The only factor present to limit the current is the RESISTANCE of the armature circuit. This resistance is very LOW. STARTING current is therefore VERY HIGH.

Motors are usually provided with some form of CURRENT LIMITING DEVICE—MOTOR STARTER—which prevents high starting current. You remove this resistance from the circuit when the motor reaches full speed.

TYPES OF MOTORS

In the SHUNT MOTOR, the field windings are connected in PARALLEL with the armature. In the SERIES MOTOR, the field windings are connected IN SERIES with the armature.

The shunt motor is a CONSTANT-SPEED motor, and you use it for constant-speed work.

The series motor is a VARIABLE-SPEED motor. It adjusts itself automatically to run slower under heavy loads, and faster under light loads. You must always connect this type of motor to a load to prevent excessive speed.

The FIELD windings of a motor may be connected in series, parallel, or series-parallel with respect TO EACH OTHER. This does not determine the type of motor. Figure 153 will show you that the method in which the armature is connected to the fields, as a group, determines the type of motor.

All STARTER motors in automobiles and airplanes are series motors. The field windings are usually connected in series-parallel connection with respect to each other. The field as a whole is in series with the armature.

The internal construction of d-c ammeters and voltmeters resembles the simple d-c motor without a commutator. In figure 154, note the internal construction of a moving coil, or D'Arsonval, meter. Nearly all d-c voltmeters and ammeters are of this type.

The coil is set on pivots and is free to move in the magnetic field established by a stationary

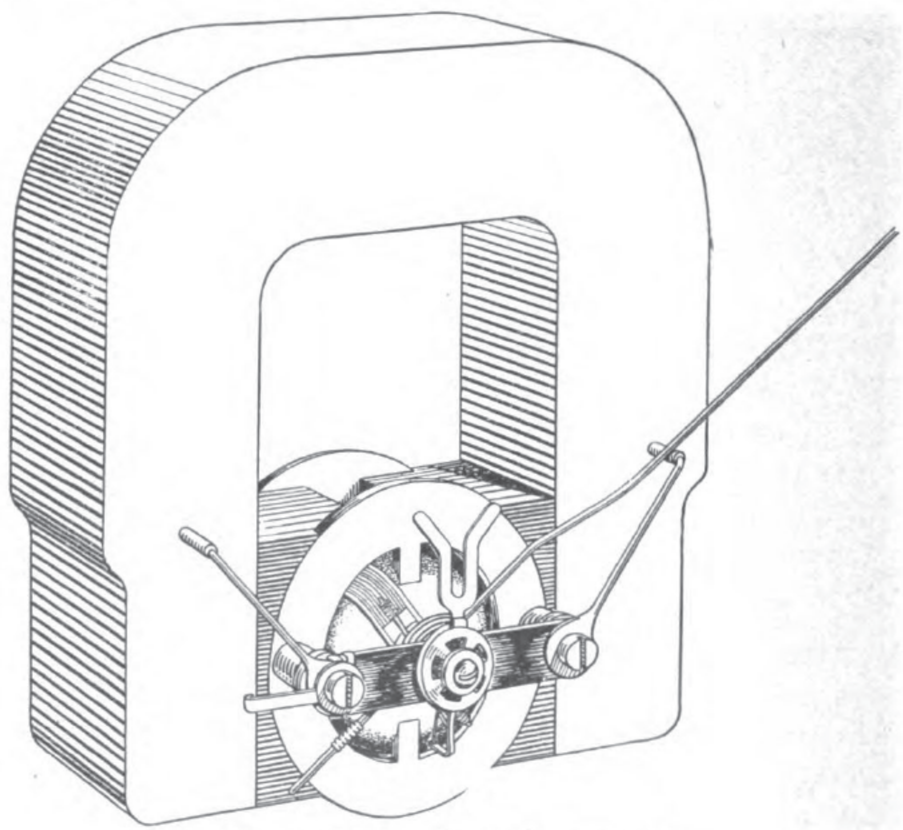
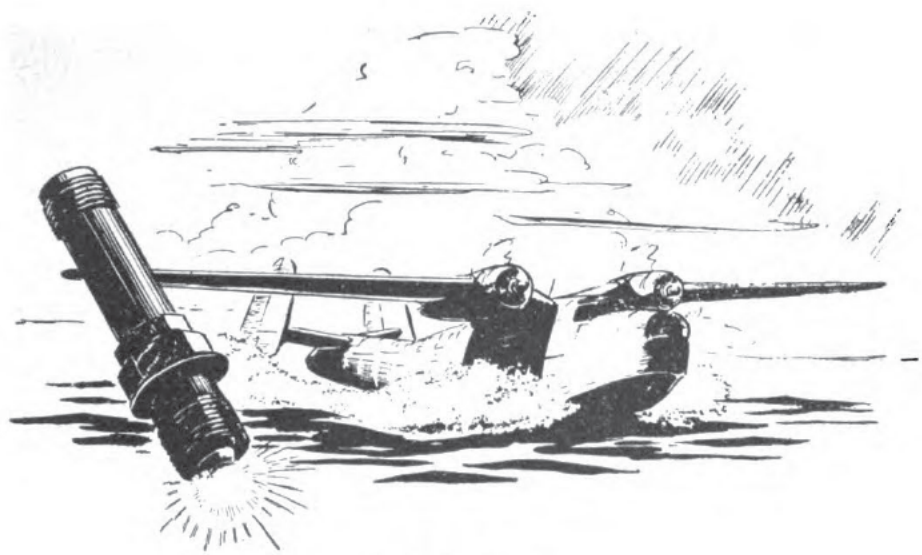


Figure 154.—D'Arsonval movement.

permanent magnet. Current flow through the coil causes it to become a temporary electromagnet. The motor action that results tends to produce rotation. Two flat spiral springs mounted on each end of the coil serve a double purpose. They lead current in and out of the coil, and they tend to keep the coil from rotating. The coil will rotate until the mechanical force of the springs balances

the magnetic force of motor action. The magnetic force produced is proportional to the current in the coil. Hence the degree of movement depends on current. A pointer attached to the coil moves over a scale and indicates the strength of the electrical quantity.

The permanent magnets in the meter must provide a powerful magnetic field of CONSTANT magnetic strength. Magnetic metals possessing high magnetic retentivity are therefore used. In addition, the moving coil rotates around a stationary iron core. The air gap between this core and the field is exceedingly small—one reason why you must handle such instruments WITH EXTREME CARE.



CHAPTER 14

ELECTROMAGNETIC INDUCTION

CHANGE CURRENT—FLUX CHANGES

Close an electric circuit and you get a flow of current. After a moment of build-up, this current has reached its maximum, which depends upon the voltage and the resistance of the circuit. During the MOMENT OF BUILD-UP of the current, the magnetic field also builds up. Circular lines of force swell outward from the wire and continue to expand until the current is at its maximum. The field flux is then stationary, and remains so, unless the current changes.

If you increase the current by stepping up the voltage or by reducing the resistance, there is a corresponding new build-up of the magnetic field. The strength of the field depends upon the strength of the current.

Reduce the current, and the surrounding magnetic field contracts or SHRINKS. Halt the current, and the magnetic field has a total collapse. A CHANGING CURRENT IS ASSOCIATED WITH A CHANGING MAGNETIC FIELD.

INDUCTION IN A SECOND CIRCUIT

When a magnetic field varies or moves so that it cuts across a conductor, an emf is induced in the conductor. If you connect the conductor in a closed circuit, you get an induced current.

In figure 155 you have two circuits close together. Close the battery circuit, current flows, a magnetic field swells out and CUTS THE SECOND CIRCUIT. An emf is induced in the second circuit. You can prove it by placing a galvanometer in the circuit. When the current reaches its steady state in the first circuit, the flux is stationary, cuts no conductor, induces no emf. The galvanometer stands at zero.

Open the battery circuit, the current falls to zero, and the flux collapses. The collapsing flux cuts through the second circuit and again induces an emf. The second induced current has a direction opposite to that of the first induced current, as indicated by your faithful galvanometer needle. When the battery current—after a split fraction of a second—has dropped to zero, the flux has disappeared and of course its induced current. The galvanometer needle truthfully points to zero.

In such a set-up, the induced emf surges up, vanishes, surges up again—that is, it pulsates as long as the make-break-make continues.

TRANSFORMERS

The circuit with the original voltage and current you call the PRIMARY CIRCUIT, and the circuit with induced emf and current you call the SECONDARY CIRCUIT. Together, such circuits can be used to make a TRANSFORMER, which transfers electrical energy from the primary to the secondary via the phenomenon of electromagnetic induction.

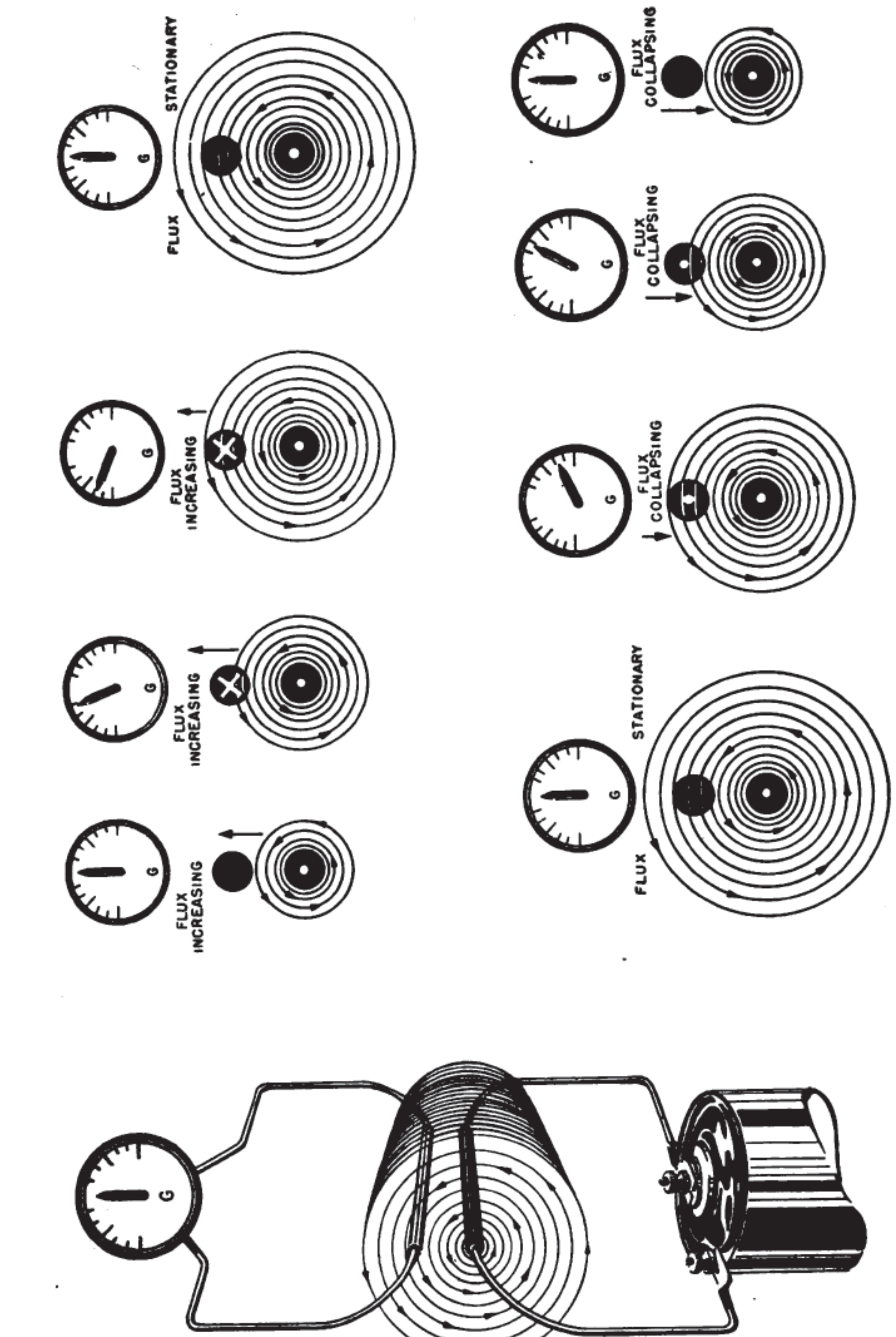


Figure 155.—Magnetic induction—flux build-up and collapse.

In figure 156, you have a diagram of a transformer, which has a PRIMARY WINDING and a SECONDARY WINDING. The use of numerous turns of wire makes possible the building up of a strong magnetic field, which cuts through the secondary coil and therein induces considerable current. The transformer in figure 156 has an AIR CORE and represents a type widely used in radio circuits.

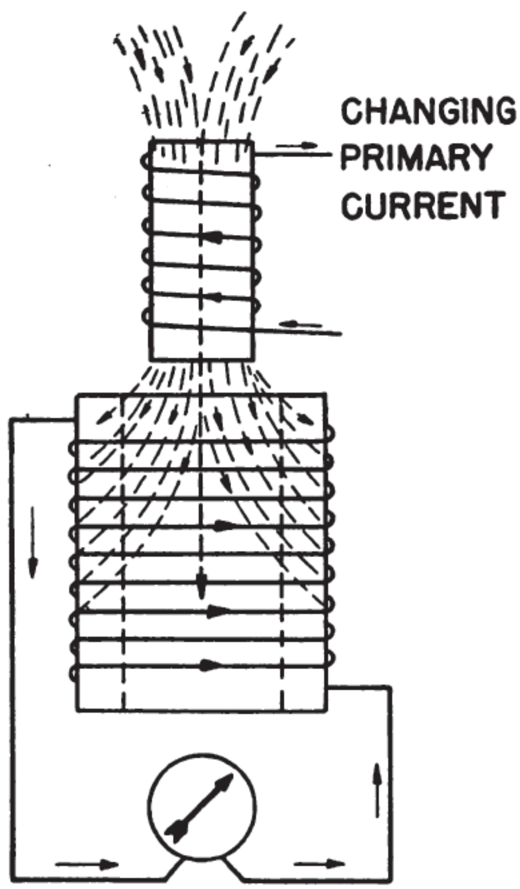


Figure 156.—Air core transformer.

You add an iron core to increase still more the amount of magnetic flux associated with the current in the primary circuit. See figure 157. With this type of transformer, the induced voltage in the secondary circuit can be made thousands of times greater than the voltage acting in

the primary circuit. Such a transformer is a STEP-UP transformer. When there are many more turns of wire in the primary than in the secondary, you have a STEP-DOWN transformer. Then you can obtain a low voltage in the secondary coil when you pass a high voltage through the primary.

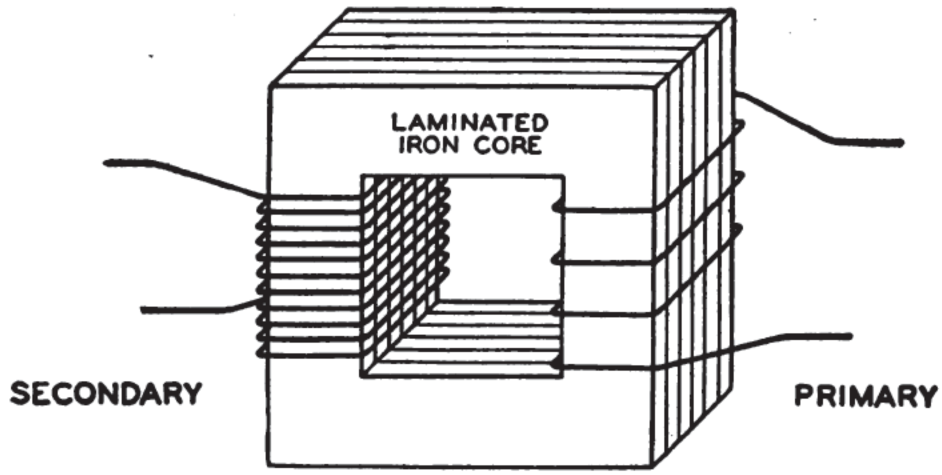


Figure 157.—Iron core transformer.

SECONDARY VOLTAGE

The secondary voltage is proportional to the number of turns on the secondary winding. That is, THE RATIO BETWEEN PRIMARY AND SECONDARY VOLTAGES IS THE SAME AS THE RATIO BETWEEN PRIMARY AND SECONDARY TURNS.

If you know the primary voltage, the number of turns on the primary winding, and the number of turns on the secondary winding, then you can readily find out the voltage induced in the secondary coil.

FORMULA.

$$\frac{E_p}{E_s}=\frac{N_p}{N_s}$$

WHEN—

E_p = primary voltage.
E_s = secondary voltage.
N_p = number of primary turns.
N_s = number of secondary turns.

FOR INSTANCE—

The primary winding of a transformer has 100 turns, the secondary has 400 turns. An emf of 110 volts is applied to the primary.

THEN—

$$\frac{E_p}{E_s}=\frac{N_p}{N_s}$$

$$\frac{110}{E_s}=\frac{100}{400}$$

$$100\ E_s=44{,}000$$

$$E_s=\frac{44{,}000}{100}\text{, or 440 volts}$$

In other words, there is a ratio of 1 to 4 between the primary and secondary turns. So there must be also a ratio of 1 to 4 between the primary and secondary voltages. This is obviously a STEP-UP transformer.

If the ratio between the primary turns and the secondary turns were 4 to 1, then the voltage in the secondary would be one-fourth of the voltage in the primary winding, or $\frac{110}{4}$, or 27.5 volts.

A. C. FOR THE TRANSFORMER

When you send a direct current through the primary winding, you build up a magnetic field. As the flux builds up you get an induced current in the secondary, but an induced current lasting

only an instant. You induce a momentary current again when you break the primary circuit and collapse the flux.

In figure 158, you have a graph showing how an alternating voltage changes continuously in strength and direction. During one cycle, the voltage builds up to a maximum, falls to zero, reverses direction, builds up to a second maximum, falls to zero. Then, to start a second cycle,

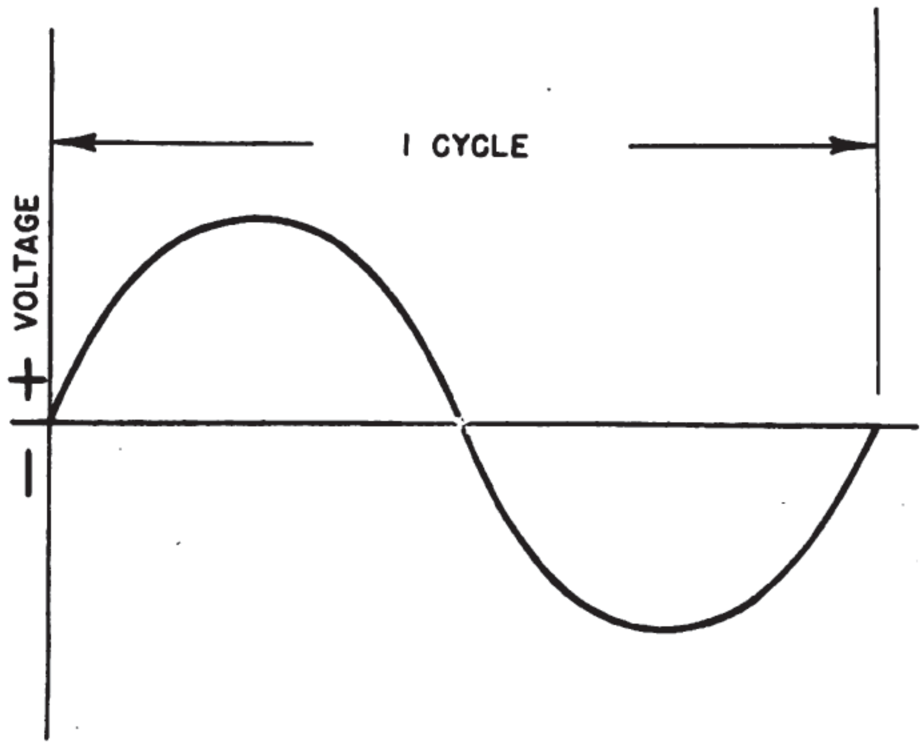


Figure 158.—Graph of a-c voltage.

it reverses direction again. Apply an alternating 60-cycle voltage to the primary, and the current in the primary changes direction 120 times per second, and, in between these changes in direction, varies rhythmically from zero to maximum to zero. The strength of the magnetic field associated with this varying current varies correspondingly. This continuously surging and collapsing field cuts the turns in the secondary and

therein induces an alternating emf of the same frequency.

The POWER TRANSFORMER transfers electrical energy from one circuit—at a certain frequency and voltage—to a second circuit at the same frequency and a DIFFERENT VOLTAGE. In a radio receiver or transmitter, the power transformer converts the source voltage—usually 110 or 120 volts, 60 cycles—to either higher or lower voltage. Power transformers having both step-up and step-down windings on the same core are widely used in radio. In receivers and transmitters, the RADIO FREQUENCY TRANSFORMER changes voltages throughout a comparatively narrow band of frequencies. The AUDIO FREQUENCY TRANSFORMER steps up audio frequency voltages over a wide band of audio frequencies.

You can obtain transformer action by means of only a single coil if you have a connection somewhere between the extreme ends of the winding. Here you have an AUTOTRANSFORMER, diagramed in figure 159. If you want to step up voltage, you use the winding between the top and one end of the primary, and the entire winding for the secondary circuit. If you desire a step-down transformer, you use the entire winding for the primary, and the section between the top and one end for the secondary. You find such transformer in both power and radio circuits.

IGNITION COILS

In all automobile ignition systems, the ignition coil has an iron core transformer. The spark that ignites the charge in the cylinders is produced by a current jumping the gap in the spark plug. This air gap has very high resistance because a very high voltage is needed to force even a small current to make the jump.

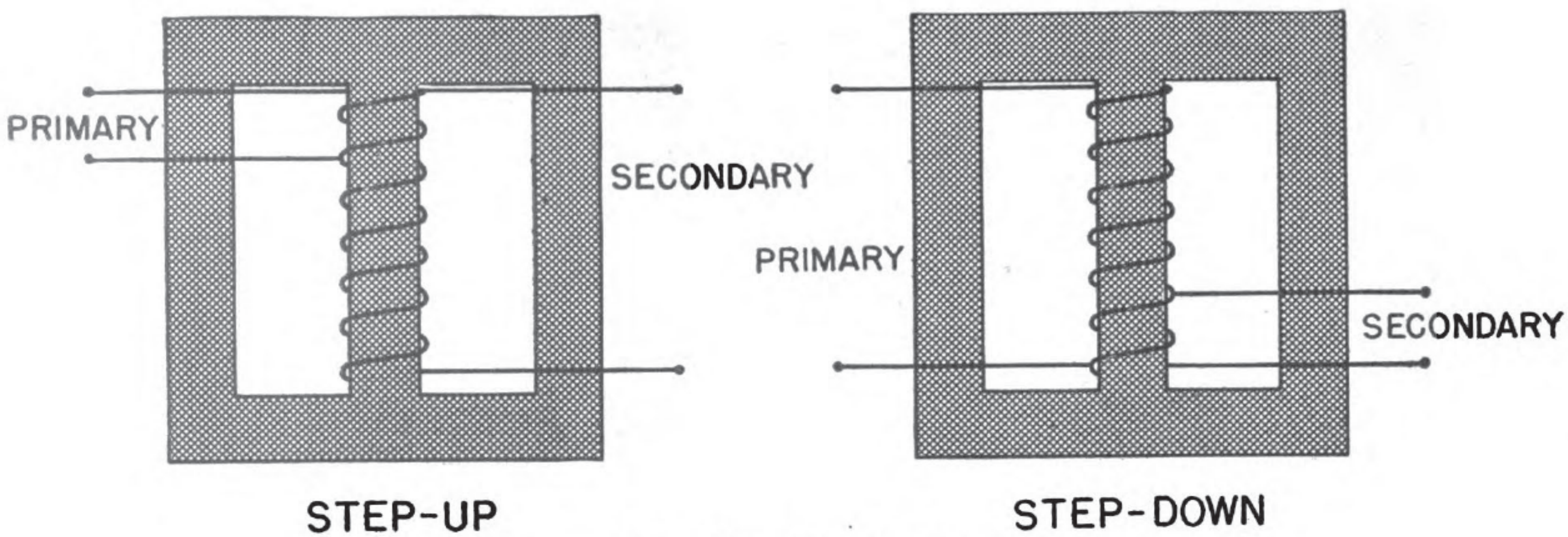


Figure 159.—Autotransformer.

The DIRECT current in the primary circuit is controlled by breaker points in the distributor. When the points close and make contact, current flows for an instant through the primary winding and a strong magnetic field is built up. At the particular moment when a spark is needed, the breaker points open and interrupt the primary current. The magnetic field collapses and induces a HIGH VOLTAGE in the secondary winding, so that an induced current is forced to make the jump across the gap.

AT ONLY TWO INSTANTS is emf present in the secondary circuit—at the MAKE and at the BREAK. At the make, the secondary voltage is not sufficient to cause a spark because of condenser action at the breaker points. So the secondary voltage at the BREAK is alone high enough to jump the gap.

With the ignition coil, you induce voltage and current at the instant only of make or break. In Fig. 160, you have an INDUCTION COIL which produces an apparently continuous spark at a gap. An interrupter circuit in the primary circuit does the trick.

A spring tends to keep closed the contact points in the primary circuit. But the flow of primary current magnetizes the core and draws the armature to it—to break the circuit at the contact points. The core flux falls almost to zero, and so the spring pulls back the armature, restores contact. The rapid repetition of this break-make results in a rapidly changing—collapsing and surging—magnetic field. The high emf induced maintains a spark across the gap while the switch is closed. The current in the secondary circuit is an irregular a. c. induced by the interrupted d. c. in the primary.

Similar vibrator, or interrupter, mechanisms can convert low-voltage d. c. to high-voltage d. c. First, an interrupter and a transformer convert low-voltage d. c. to high-voltage a. c. Then a rectifier circuit changes this high-voltage a. c. to high-

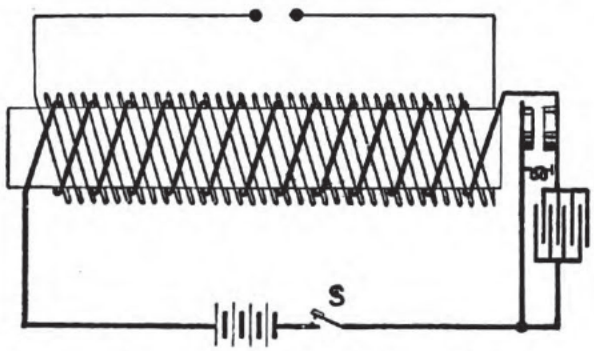


Figure 160.—Induction coil.

voltage d. c. Practically all automobile radio receivers use such vibrator rectifier.

INDUCING VOLTAGE BY CHANGING RELUCTANCE

In figure 161, you have a battery connected to a winding on an iron core. A second winding on

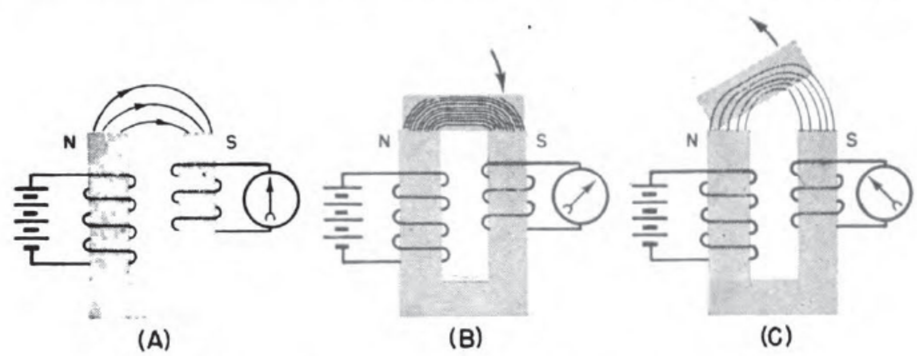


Figure 161.—Inducing voltage by changing reluctance.

this core is connected to a sensitive voltmeter. When you close the battery circuit, a current flows through the winding and builds up a magnetic field which cuts through the other winding on the core. The emf induced in the second winding causes a momentary deflection of the

voltmeter needle. Of course, the needle goes back to point to zero as soon as the field reaches its steady state.

Place an iron bar across the ends of the core and the voltmeter deflects again. With the iron bar, you have changed the magnetic reluctance—in fact, you have decreased it. What effect does decreased reluctance have? It causes an increase in magnetic flux. And this flux cuts the secondary and induces a voltage in it. The deflection of the meter is to the right, in this case, and is again only momentary. As soon as the magnetic field becomes constant, the voltage drops to zero. Remove the iron bar, and the meter is deflected in the opposite direction. Now the reluctance INCREASES, the magnetic field decreases, and this partial collapse induces an emf in the secondary winding. The emf, of course, is in a direction opposite to that of the emf induced by the expanding magnetic field.

SIMPLE ALTERNATORS

You can provide a transformer with an iron ROTOR to make a SIMPLE ALTERNATOR. Figure 162

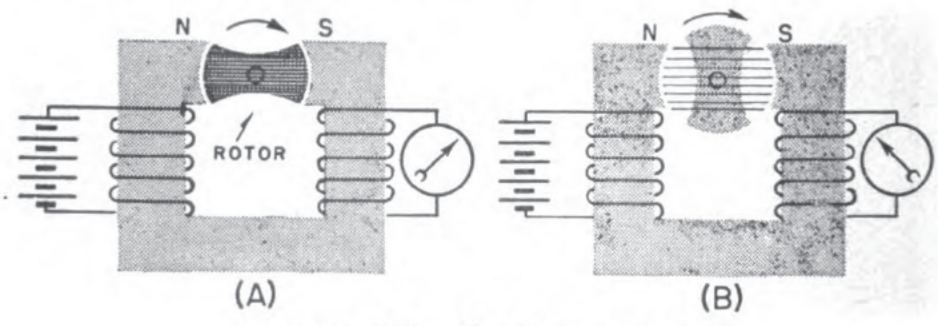


Figure 162.—Simple alternator.

gives you the idea. You use a battery and a primary winding to establish a magnetic field around the iron core. The reluctance of this core, of course, affects the strength of the field. When

you have the rotor in position (A), you have a strong magnetic field because an all-iron magnetic CIRCUIT has a low resistance path. Put the rotor in position (B), and you weaken the field because you introduce a high reluctance air-gap. Revolve the rotor, and you have an alternately surging and collapsing magnetic field that cuts the secondary winding. The frequency depends on the speed of the rotor.

CHAPTER 15

INDUCTANCE AND CAPACITANCE

VOLTAGE THAT OPPOSES ITSELF

How can a voltage act against itself? Just look at figure 163. There you have a coil and a battery. Note the magentic conditions at the instant you close the switch. For simplicity in the drawing, only a portion of the magentic field that exists around any current-carrying conductor is shown expanding from a point on one of the turns. As it surges out, the flux from this turn cuts across the adjacent turn and induces a voltage in that adjacent turn. What is the direction of this induced voltage? Opposite to that of the voltage you apply from the battery. So here you have a condition in which a voltage opposes itself by inducing COUNTER EMF.

Counter emf is always LESS THAN the impressed voltage and lasts only a moment, only as long as the field expands. What happens to the current? Well, it builds up more gradually than it would if there were no counter emf to act in the opposite direction. The CURRENT LAGS, does not reach the steady state value until the magnetic field becomes stationary and no counter emf is present in the coil. If you had a coil with more turns of wire, you would have flux cutting across more turns to induce greater counter-emf.

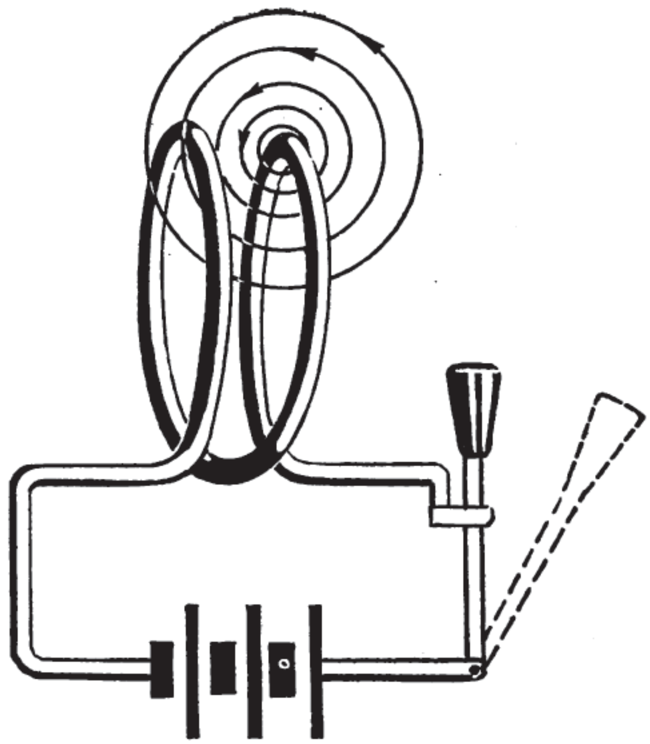


Figure 163.—Voltage of inductance—counter emf.

BOOST

Open the switch. You collapse the magnetic field because it cuts through the turns of its OWN coil. Again you induce voltage, this time IN SUCH A DIRECTION THAT THE CURRENT FROM THE BATTERY IS GIVEN A BOOST. So the current decreases gradually, as it would not without the induced emf which momentarily helps to maintain it.

INDUCTANCE, OR SELF-INDUCTION

The induction of emf in the same coil as the applied emf is known as INDUCTANCE, or SELF-INDUCTION. Inductance opposes current change. The counter-emf resists the building up of the current in the coil at the moment when the circuit is closed, and the emf of inductance tends to boost

current and prolong its decrease at the moment when you break the circuit.

In ordinary d-c circuits, inductance is significant only during the rise of current when the circuit is closed or during the fall of current when the circuit is broken. No inductive conditions are associated with a steady current, and you know why. In a-c circuits, the current is ever-changing and the inductance of the circuit is of outstanding importance.

The emf of inductance depends not only on the number of turns but also on the nature of the core—AIR CORE or IRON CORE. If you provide an iron core, you get a greater inductive effect. A closed magnetic CIRCUIT produces maximum self-induction because of low magnetic reluctance of such a magnetic CIRCUIT.

RISE OF CURRENT IN INDUCTIVE CIRCUITS

Compare the rise of currents in three coils, figure 164, which have exactly the same resistance but different magnetic features.

Close the switch, and you impress 10 volts across all three coils. In the AIR COIL (*A*) there is prac-

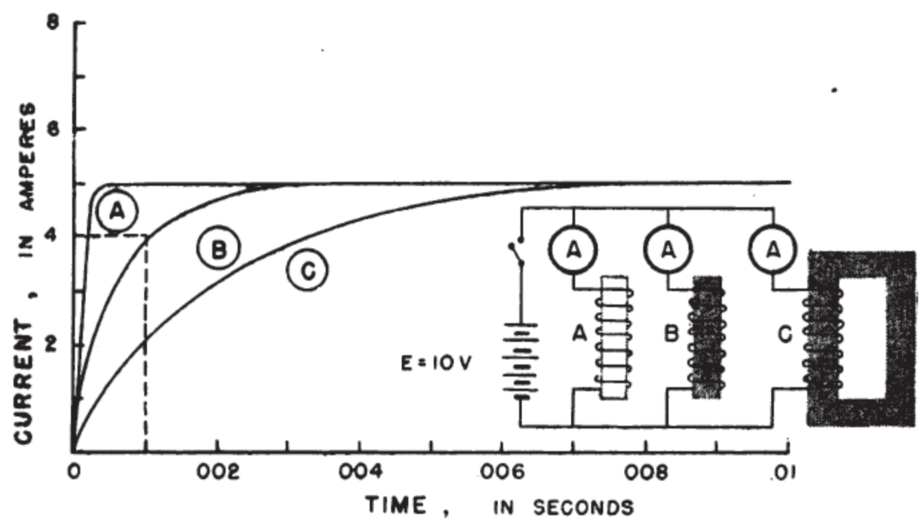


Figure 164.—Rise of current in inductive circuits.

tically no inductance and the current rises almost instantly to its maximum of 5 amperes. In the OPEN IRON-CORE COIL (*B*), the current rises more slowly to its maximum because of the counter emf developed in the coil by the expanding magnetic field. In the CLOSED IRON-CORE COIL, (*C*), the rise of current is still more gradual because of the high inductance associated with a closed-core magnetic field. Look at the graph to find the values of the counter voltages.

In figure 165, you have a coil with an open iron core. Close the switch, and after 0.001 second the current is 4 amperes at this particular instant. Against the resistance of 0.5 ohm, this current can be obtained with an impressed voltage of 8 volts if there were no counter-emf.

Because the impressed voltage is actually 10 volts, the counter-emf at this instant must be 10 minus 8, or 2 volts.

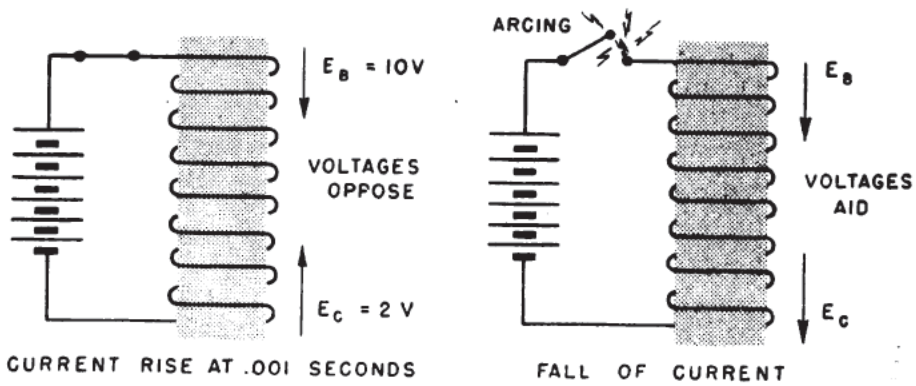


Figure 165.—Effects of counter-emf.

Open the circuit, and the magnetic field collapses, so that a counter-voltage is induced in the same direction as the applied voltage. This counter-voltage may be several hundred times greater than the applied voltage. Hence, it will produce a momentary arc at the switch contacts.

In an inductive circuit, the current rises and

falls more gradually than in a resistive, or non-inductive, circuit. The inductance always opposes any force that tends to CHANGE the EXISTING CURRENT in the circuit.

MUTUAL INDUCTION

When voltage is induced in one circuit by current changes in a neighboring circuit, you have what is known as MUTUAL INDUCTION.

You change current by closing or opening the circuit or by varying the load in d-c circuits. Alternating current causes continuous variation of flux. In the transformer, you put to use such continuous mutual induction. Sometimes, however, the voltages of mutual induction upset the operation of neighboring circuits. MAGNETIC COUPLING is another term for mutual induction.

UNITS OF INDUCTANCE

The unit of inductance is known as the HENRY. A circuit has an inductance of 1 henry when a current change at the rate of 1 ampere per second induces a counter-emf of 1 volt in the circuit. In many circuits, the henry is too large a unit. Then you use the MILLIHENRY, one-thousandth of a henry. A MICROHENRY is one-millionth of a henry.

LENZ'S LAW

Here's another law to watch out for—Lenz's law.

IN ALL CASES OF ELECTROMAGNETIC INDUCTION, THE DIRECTION OF THE INDUCTED CURRENT IS SUCH AS TO SET UP A MAGNETIC FIELD WHICH WILL RESIST THE MOTION PRODUCING THE CURRENT.

For instance, as you see in figure 166, when you induce a current by moving a magnet into a coil, this current sets up a magnetic field whose *N*

pole repels the N pole of the moving magnet. And when you withdraw the magnet from the coil, the induced current is now in the opposite direction and sets up a magnetic field whose S pole attracts the N pole of the magnet. Note

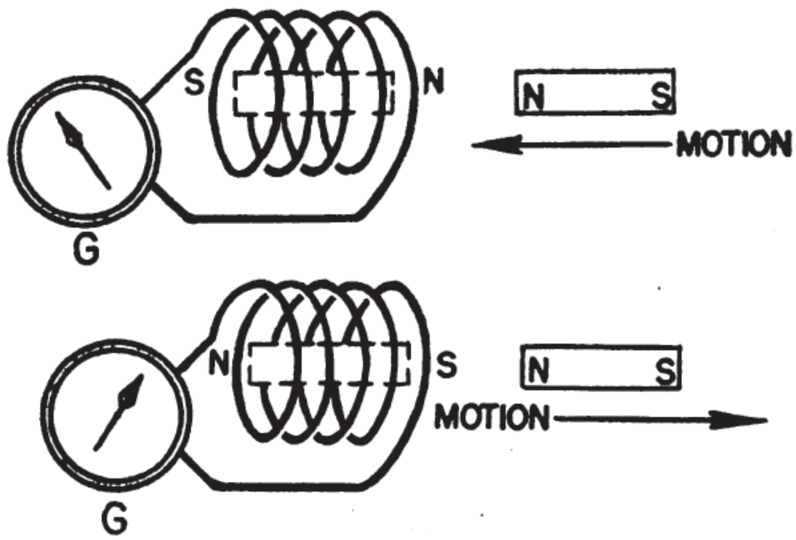


Figure 166.—Len's law.

this this attraction tends to oppose the withdrawal of the magnet.

CONDENSER ACTION

As you learned at the end of Chapter I, a condenser consists of conductors, or plates, separated by some insulator. Another name for this insulator is a DIELECTRIC. You use a condenser to reduce arcing at contact points, to counteract the objectionable effects of inductance, and to obtain PULSES of current. In figure 167, you can see the action of a condenser in an electrical circuit. When you close the battery circuit in (*A*) by means of switch *S*, you get a MOMENTARY flow of current as indicated by the deflection of the galvanometer. Though the current is only momentary, it does charge the condenser. That is, the emf of the battery forces electrons to flow away

from Plate P_1 and on to plate P_2 until the difference of potential between the plates is equal to the emf of the battery. Plate P_1 is positive because of the deficiency of electrons, whereas P_2 is negative because of the excess of electrons piled up on it. Theoretically, the plates would remain thus charged as long as the battery emf is applied, or until the plates are connected together through a circuit.

When the switch S connects the plates of the condenser together, as you see in (*B*) of figure 167, the galvanometer is again momentarily deflected in a direction opposite to that in (*A*).

The current supplied to the circuit by the condenser as it discharges is in a direction opposite

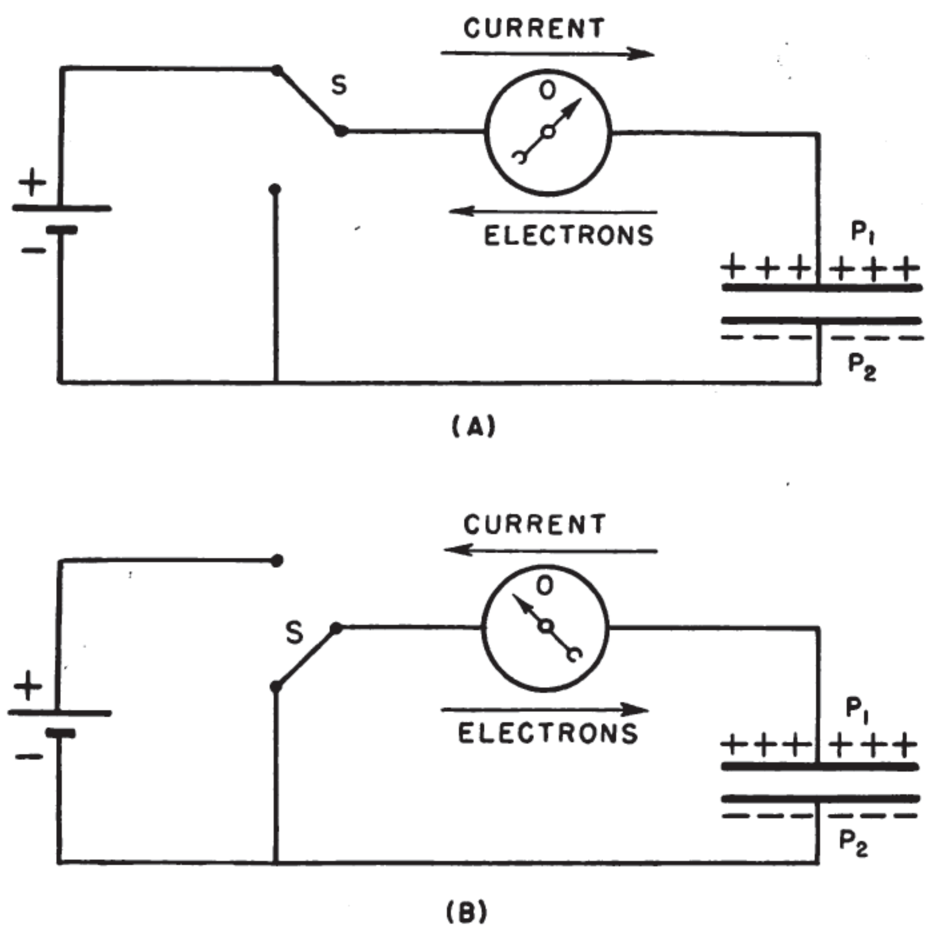


Figure 167.—Condenser action.

to that of the charging current supplied by the battery. As the condenser discharges, the electrons on plate P_2 move toward the positive plate P_1. When both plates again have a neutral charge, the condenser is in a discharged state.

CAPACITANCE

The greater the electromotive force, the stronger is the dielectric field, or electrostatic field, of a condenser and the greater is the counter electromotive force which opposes the applied voltage. Thus the condenser acts to oppose any change in the supply voltage. This property which opposes any change in voltage is CAPACITANCE.

The unit of capacitance is a FARAD. This unit is too large for practical use, and so the capacitance of most condensers is measured in MICROFARADS. The micro-farad is one-millionth of a farad. In certain radio circuits, condensers are so small that their capacitance is measured in MICRO MICRO-FARADS, or one-millionth of a microfarad.

The capacitance of a condenser is directly proportional to the area of the plates and inversely proportional to the distance between the plates. The capacitance is also affected by the type of material used for a dielectric. A condenser using mica for a dielectric has a larger capacitance than one using air for its dielectric.

In figure 168, you see the principal types of condensers used in electrical circuits.

VARIABLE condensers used in communication circuits have air for the dielectric. In general, these condensers consist of two sets of plates insulated from each other. The plates are so arranged that one set of plates can be moved in relation to the other set. The stationary plates

are known as the stator, and the movable plates, the rotor. Maximum capacity is obtained when the rotor and stator are nearest to each other (rotor plates completely in). The capacitance of standard-type variable condensers ranges from a few micro micro-farads to several hundred micro micro-farads.

MICA condensers have high voltage ratings. But they are generally limited in capacitance to

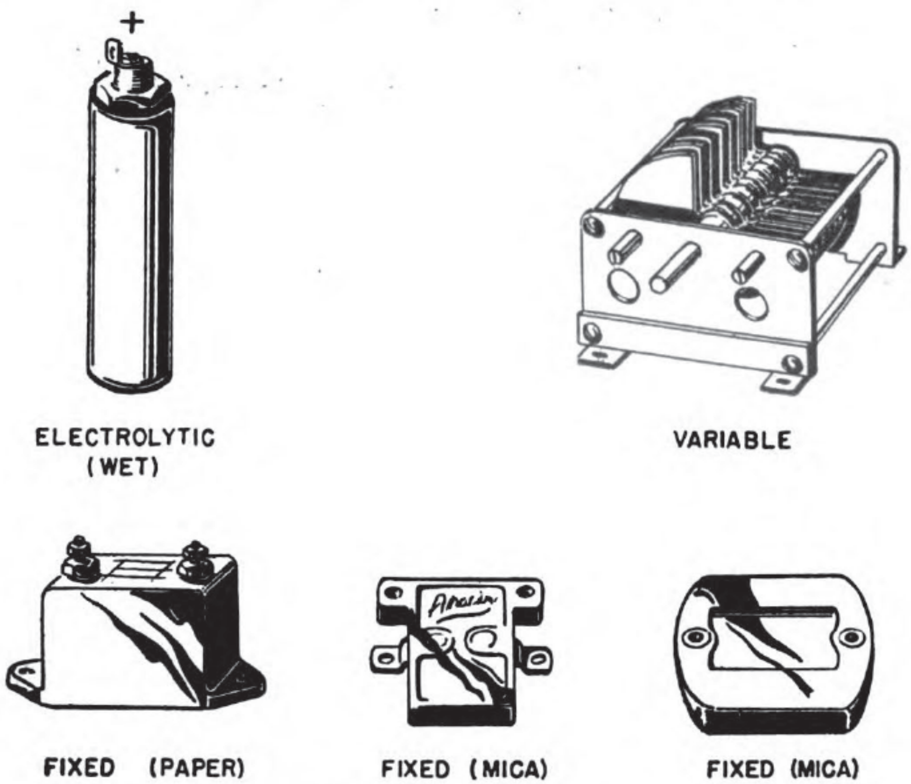


Figure 168.—Condensers.

about 0.05 micro-farad. Paper condensers consist of sheets of tinfoil and paper rolled together and impregnated with wax to exclude moisture. Condensers of this type vary in capacity from 0.1 to 2 micro-farads. When you need large capacity and high voltage ratings, you use oil-treated paper.

The ELECTROLYTIC condenser uses a thin film of oxide and gas as a dielectric. This oxide and gas

are formed when voltage is applied to the unit. One of the conductors is usually aluminum foil. The other is the electrolyte. Electrolytic condensers are manufactured both in the wet and dry (paste) types. Because of the extremely thin film of dielectric, very large values of capacitance without excessive size can be obtained. Attention must be given to the PROPER POLARITY of these condensers when they are connected in the circuit.

VOLTAGE RATING

Just as the current flowing in an induction coil creates a magnetic field of force, the difference of

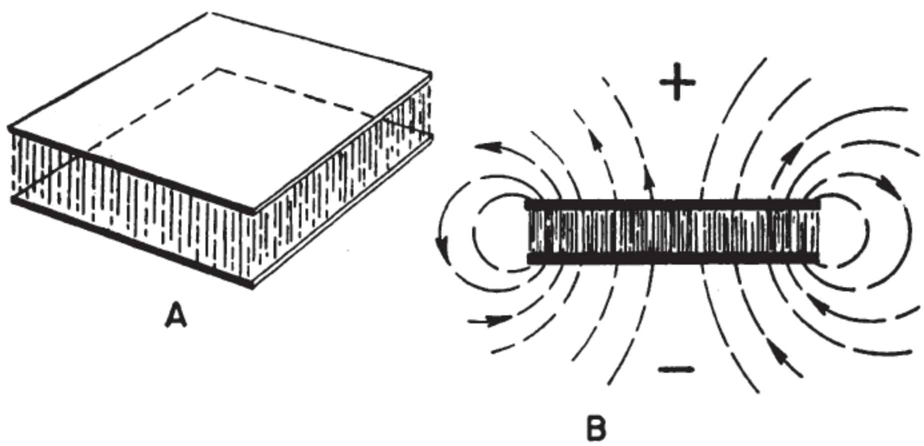


Figure 169.—Electrostatic field in a condenser.

potential between the plates of a condenser creates an electrostatic field such as you see diagrammed in figure 169.

This field strength will increase with the difference of potential between the plates. If you use a condenser on a voltage higher than its rating, the strength of this electrostatic field tends to break down the dielectric.

You must always guard against the possibility of a dielectric break-down in any condenser. In most cases, break-down is caused by the application of a voltage greater than the rated voltage of

the condenser. When the dielectric is broken down, the condenser plates usually make contact and the condenser will not take a charge. Occasionally, the dielectric is ruptured but a short has not developed between the plates. In this case, a condenser may pass a test at reduced voltage. Therefore, the condenser should be tested at or slightly above the voltage at which it is to be used.

Mica is used as a dielectric material for condensers because thin sheets of this material withstand very high voltages without a break-down. When you use mica, you can place condenser plates close together and so get a small condenser which has considerable capacity and which takes high-voltage currents.

CONDENSER DISCHARGE SHOCKS

The charge stored in a condenser can be of sufficient strength to cause severe shock, and even electrocution. So handle with care any condenser charged on a high-voltage circuit. Be SURE that the terminals of the condenser are short-circuited before you touch the condenser. If you want to play very safe, short-circuit the condenser SEVERAL TIMES with a few seconds interval between short circuits. The charge is stored in the dielectric, and often a quick short circuit does NOT remove the charge COMPLETELY.

CONDENSERS IN SERIES AND PARALLEL

Condensers are often connected in series and parallel combinations to obtain capacitance values greater or lower than that of a single individual condenser.

The parallel connection of condensers yields a total capacitance which is equal to the sum of the capacitances of the individual condensers. In a

parallel combination, all condensers receive the same applied voltage.

FORMULA—

$$C_T = C_1 + C_2 + C_3$$

WHEN

C_T = Total capacity.
C_1 = Capacity of condenser No. 1.
C_2 = Capacity of condenser No. 2.
C_3 = Capacity of condenser No. 3.

The SERIES combination of condensers yields a total capacitance less than the lowest capacitance value of any condenser in the combination. Condensers are usually connected in series when the applied voltage in the circuit is greater than the voltage rating of the individual condensers. In this case, the condenser combination as a whole has a lower capacitance value but higher voltage rating.

The capacitance of a series combination can be calculated by use of a reciprocal formula similar to that used for total resistance of parallel resistors—

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

CONDENSER ACTION ON ALTERNATING CURRENT

When a d-c voltage is applied to a condenser, a momentary flow of current takes place during the time-interval required to charge it. An ammeter placed in such a circuit will deflect momentarily. If you apply an alternating voltage to the condenser, an alternating current appears to flow continuously in the circuit. An a-c ammeter in this circuit will register a continuous value of alternating current. Actually, NO current passes

THROUGH the dielectric. Here's the explanation. The electric polarity of an alternating voltage changes periodically. On the positive alternation, the condenser charges. When the impressed voltage decreases, the condenser loses its charge by discharging into the voltage source. On the negative alternation, the condenser is charged in the opposite direction, only to discharge again when the impressed voltage again decreases in magnitude. Although electrons do not actually pass through the dielectric, this continuous alternating loss and gain of charge is IN EFFECT an alternating current.

CHAPTER 16

SOUND

CAUSE

Within an airplane, you use an ICS—intercommunication system—to speak with other crew members. The radio transmitter and receiver make it possible for you to communicate with other airplanes and with your base of operations. In such communication, you use sound waves to affect electrical devices, which at a distance from the speaker recreate sound waves almost exactly like those of the speaker's voice. You can also use reflection of sound waves to detect submarines. Similarly, on board ship, sound waves are reflected from the ocean bottom to find out the depth.

Sound waves are caused by vibrating objects, such as your vocal cords. Touch the cone of a loud speaker in action. You can feel the vibra-

tions that set sound waves going in all directions.

Throw a pebble or a beer bottle into a pool. A series of circular waves travel away from the disturbance. In figure 170, you have such waves diagrammed as though seen in cross section, from the side.

Observe that the water waves are a succession of CRESTS and TROUGHS. The WAVELENGTH is the distance from the crest of one wave to the crest of the next wave. Water waves are known as TRANSVERSE waves because the motion of the water molecules is up and down, at right angles to the direction in which the waves are traveling. A

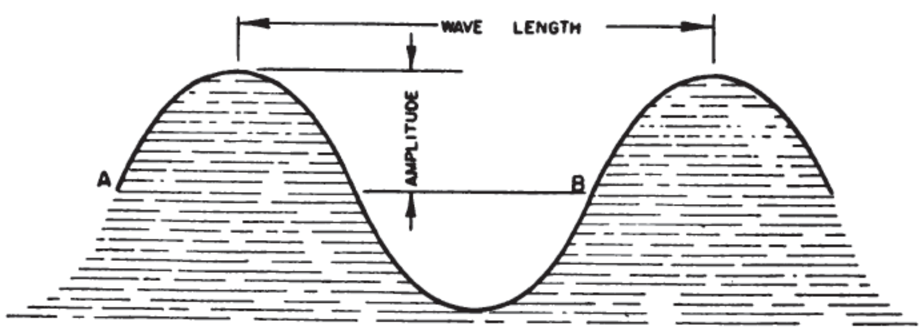


Figure 170.—Transverse waves.

cork on the water bobs up and down as the waves pass by. The AMPLITUDE of a transverse wave is HALF the distance—measured vertically—from crest to trough, and serves to indicate the INTENSITY, or "violence," of the wave motion.

SOUND WAVES—LONGITUDINAL WAVES

Sound waves are LONGITUDINAL or COMPRESSION waves, set up by some vibrating object, such as the cone of a loudspeaker. In its forward movement, the vibrating cone of a loudspeaker compresses the air molecules lying against the cone, and thus produces an area of high air pressure, or a CONDENSATION.

Air is elastic. So, on the backward movement of the cone, the air molecules move apart, to produce an area of low pressure, or a RAREFACTION. Next, the air in the first condensation expands, and thus compresses the air molecules immediately

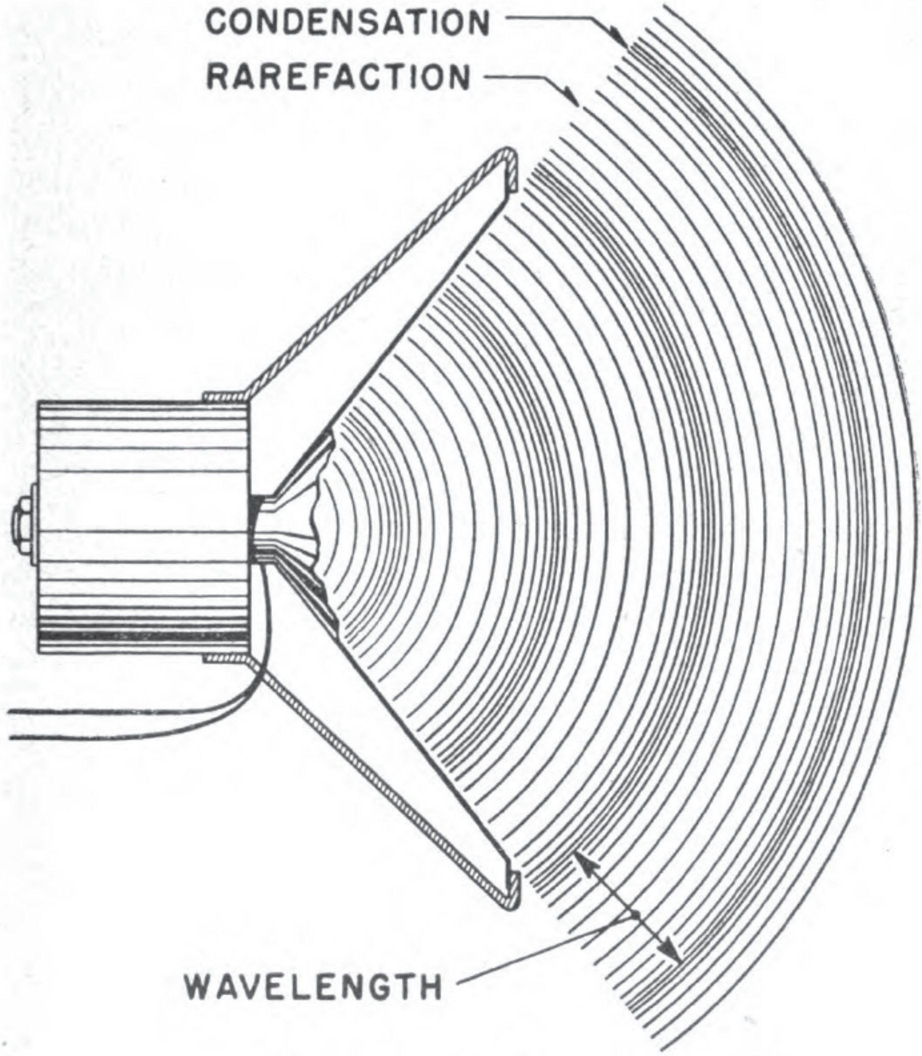


Figure 171.—Sound waves.

in front of it, to cause a second condensation farther out. Repetition of this action results in the setting up of a spreading series of condensations and rarefactions. In figure 171 note that the CONDENSATIONS are represented by dark rings. As the sound waves spread out, their energy is at

the same time spread through an increasingly large area, and the wave motion at a distance is weaker.

The wave length is the distance from one point of maximum condensation to the next such point. The amplitude is one HALF of the distance through which the vibrating source of the sound waves moves. The greater the amplitude, the greater the intensity, or loudness of the sound.

You can send sound waves through all gases, liquids, and solids. But NOT through a vacuum, because there are no molecules in a vacuum to be subjected to alternate compression and rarefaction.

In different substances, sound travels at different speeds. In air, the velocity of sound is approximately 1,090 feet per second at 32° Fahrenheit. For each 1° rise in Fahrenheit temperature, the velocity is increased by 1.1 feet per second. For instance, at 72° Fahrenheit, sound travels at the rate of $1{,}090+40\times1.1$), or $1{,}090+44$, or 1,134 feet per second.

In pure water, the velocity of sound is approximately 4,708 feet per second. In sea water, the velocity depends upon salt content (salinity), pressure, and temperature.

SOUND REFLECTION

An echo, as from a cliff, is reflection of sound waves, and is produced when the reflecting surface is large in comparison with the wave length of the sound. All underwater detection devices make use of sound reflection. If you know the speed of the sound and wave and the time required for reflection, you can easily and accurately get the distance of the reflecting object. See figure 172. In the instance of the FATHOMETER, you get the depth

by timing the reflection of a sound signal sent to the ocean floor. The time required for the signal to reach the bottom and return is automatically recorded on a scale graduated in fathoms. A FATHOM is 6 feet.

FOR INSTANCE—

You send out a sound signal through the water, and 2.1 seconds later you receive an echo from a metallic object—a submarine, it may be. If the

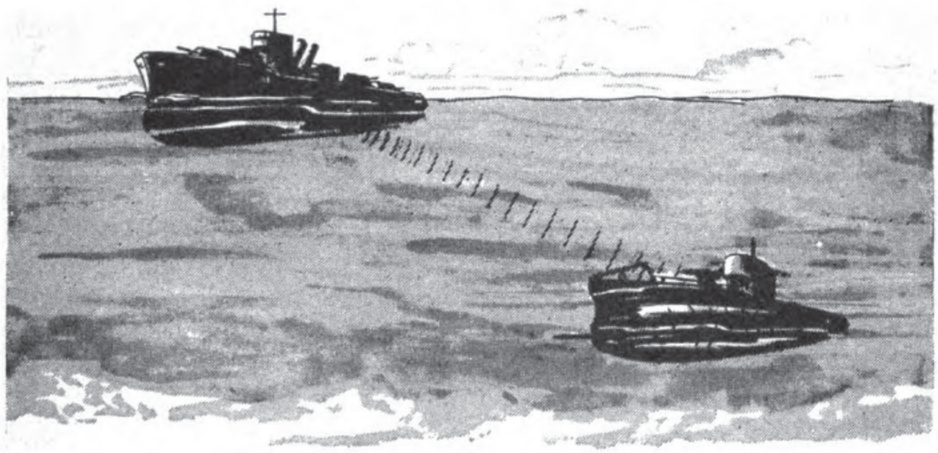


Figure 172.—Principle of sound detection.

sound wave has traveled at a speed of 4,750 feet per second, how far away is the object?

TOTAL DISTANCE the sound traveled $=4{,}750\times 2.1=9{,}975.0$ feet. (Out and back.)

DISTANCE OF OBJECT $=9{,}975\div 2=4{,}987.5$ feet.

CHARACTERISTICS OF SOUND

The explosion of shells in a barrage causes NOISE—that is, sound having no regular pattern of vibrations.

A MUSICAL NOTE has a pattern of regular vibrations. Such sounds have three characteristics—PITCH, INTENSITY (loudness), and QUALITY. An object that vibrates many times per second produces a sound with a HIGH pitch, as in the in-

stance of a whistle. The slower vibration of the heavier wires within a piano causes a LOW-pitched sound. Thus the FREQUENCY of vibrations determines the pitch. When the frequency is low, the sound waves are long, and when it is high, the waves are short. The velocity is not affected by the pitch. Otherwise, at a distance of only a few dozen feet from an orchestra, you would hear a dismal jumble of sound waves all out of step. Sound whose frequency lies between 20 and 20,000 vibrations per second may be audible, depending upon the keenness of hearing.

You control the loudness, or INTENSITY, by controlling the AMPLITUDE. You can produce a weak sound by means of a loudspeaker cone, and feel the slight vibration by touching the cone with a fingertip. Increase the loudness of the sound, and you can note the much greater movement of the cone though the rate of vibration is not increased.

You recognize your girl's voice by its quality, which depends upon complicated wave forms, created by the combination of several different types of sound waves. You can build up a tone having any desired quality by combining pure tones in suitable proportions. Sound together just the right organ pipes and you can imitate any vowel sound. Two notes of the same pitch played on different musical instruments differ in quality because lesser vibrations are superimposed upon the fundamental vibration. The fundamental is the vibration with the lowest frequency.

WAVE LENGTH = VELOCITY/FREQUENCY

If you set a loudspeaker cone to vibrating at the rate of 545 vibrations per second, and if the temperature is 32° Fahrenheit, the first wave will be 1,090 feet away at the end of the first second.

Between the cone and this wave, there will be 500 other condensations. You can see that the wave length—the distance from a point of maximum condensation to the next point of maximum condensation—must be $1{,}090 \div 545$, or 2 feet, because there are 545 condensations extending through a distance of 1,090 feet. The wave length can always be found if you know the frequency and the velocity.

FORMULA

$$\text{Wave length} = \frac{\text{velocity}}{\text{frequency}}$$

Now, suppose that the wave length is 4 feet and the frequency is 275 vibrations per second, what is the velocity?

$$4 = \frac{\text{velocity}}{275}$$

$$\text{or } 4 \times 275 = \text{velocity}$$

$$1{,}100 \text{ feet per second} = \text{velocity}$$

Similarly, if you know the wave length and the velocity, you can find the frequency.

As you see in figure 173, a simple telephone consists of a transmitter, battery, line wires, and telephone receiver. The transmitter has a flexible diaphragm attached to a carbon button. The button presses against a mass of carbon granules enclosed in a current-conducting container. When sound waves strike the diaphragm, it vibrates at the same frequency as the sound.

Vibration of the diaphragm alternately compresses and loosens the carbon grains. Compression of the carbon decreases the resistance of the microphone. Lessening the pressure on the carbon increases the resistance of the microphone.

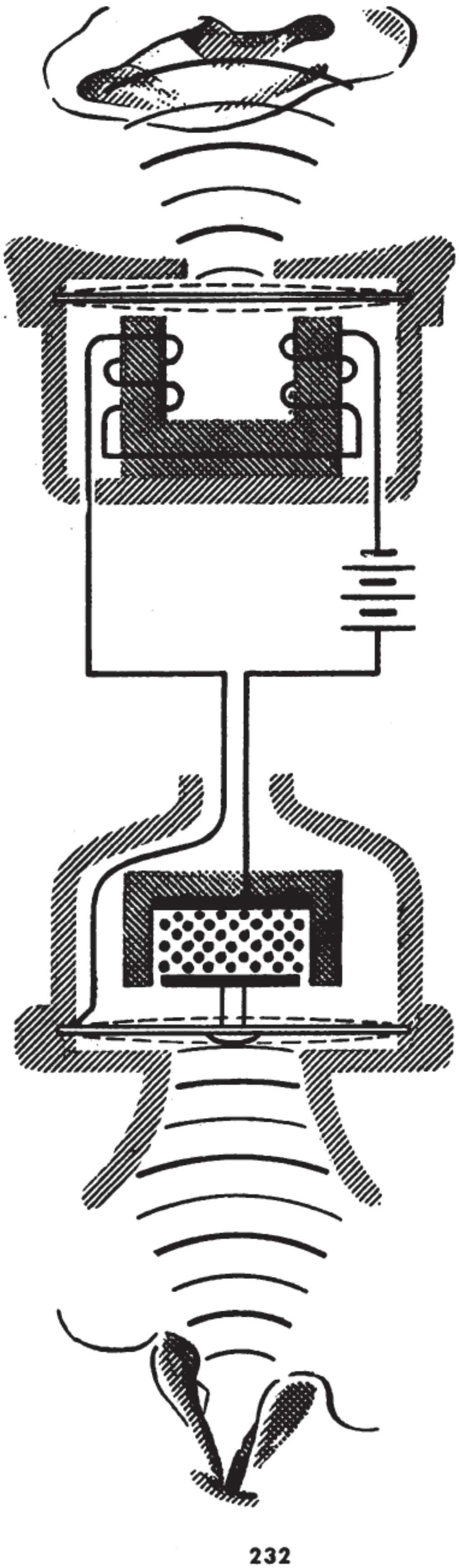


Figure 173.—The simple telephone.

Thus the resistance of the microphone varies according to the rate of vibration of the diaphragm.

When the resistance is decreased, the current increases. When the resistance is increased, the current decreases. Hence the current varies according to the rate of vibration of the diaphragm.

The receiver has a U-shaped permanent electromagnet with an iron diaphragm held just out of contact with the pole pieces. Current passing through the microphone also passes through the electromagnet of the receiver. Because this is a series circuit, the current strength in both devices is always the same. Any change in current strength in the microphone causes a corresponding change in current strength in the receiver. The position of the iron diaphragm in the receiver is determined by the electromagnet, whose magnetic strength varies with the strength of the current through the receiver. Thus changes in current that are caused by vibration of the transmitter diaphragm will make the receiver diaphragm vibrate with the same frequency.

In vibrating, the receiver diaphragm sets up sound waves, condensations, and rarefactions, that are replicas of those striking the transmitter. The loudness, or volume, of sound reproduced depends on the amplitude, or intensity of sound, at the transmitter. A sound of high amplitude causes the diaphragm to move a greater distance on either side of the neutral position. In figure 174, you can see how diaphragm movement in low-amplitude vibration differs from diaphragm movement in high-amplitude vibration. You can also see the changes in current strength that occur when sounds of different amplitudes and frequency impinge on the transmitter. In both (*A*) and (*B*) of figure 174, the horizontal axis designates time.

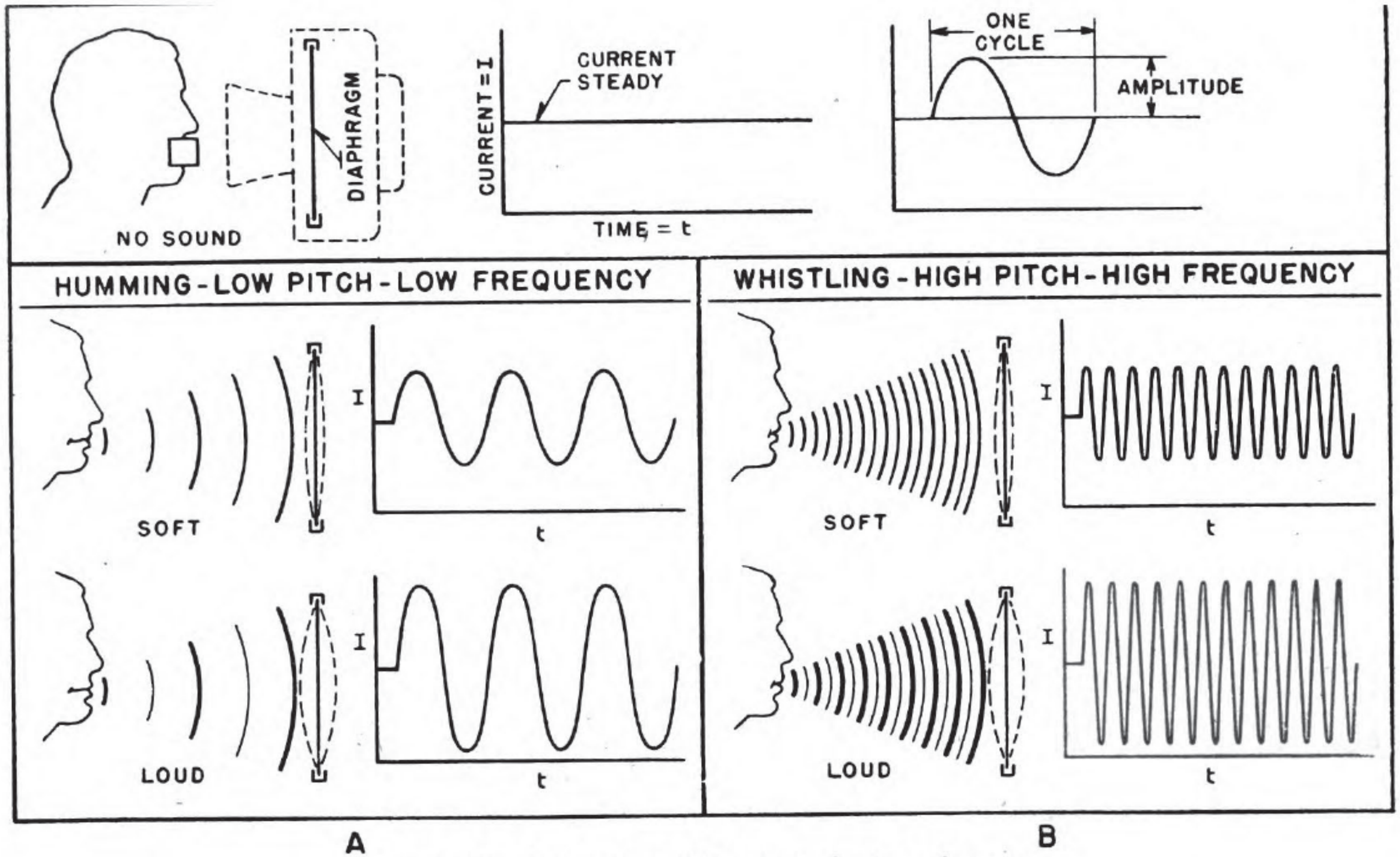


Figure 174.—Sound wave frequency and current frequency.

TRANSMISSION DISTANCE

With the simple telephone system, you can transmit sound over short distances only. The intensity of sound produced by the receiver depends upon the magnitude of current change rather than on the actual magnitude of the current. Current change depends upon the change in resistance of the entire circuit. But the changing resistance of the microphone is the only factor that produces any change in circuit resistance. If you use long lines, you discover that the microphone resistance becomes an insignificant part of the total circuit resistance and can cause only tiny current changes—too tiny to create audible movement in the receiver diaphragm.

You can increase the range of the simple telephone circuit by use of an induction coil, or transformer. In figure 175, you see the basic circuit of a local battery system. When your voice causes a pulsating current (d. c.) to flow through the primary winding of the induction coil, a pulsating magnetic field is set up around the primary. The field expands and collapses at a rate determined by the vibrations of your voice that impinge on the microphone. Consequently, you induce an a-c voltage in the secondary winding. The frequency of the induced voltage in the secondary winding is the same as the frequency of the vibrations of your voice. The step-up ratio in the coil provides voltage sufficient to overcome the resistance in a line several miles long. This induced voltage produces a current with the same frequency, and so actuates the receivers at both ends of the line.

AUDIO AMPLIFICATION

You do extend the range of communication by an induction coil, BUT long distance telephony

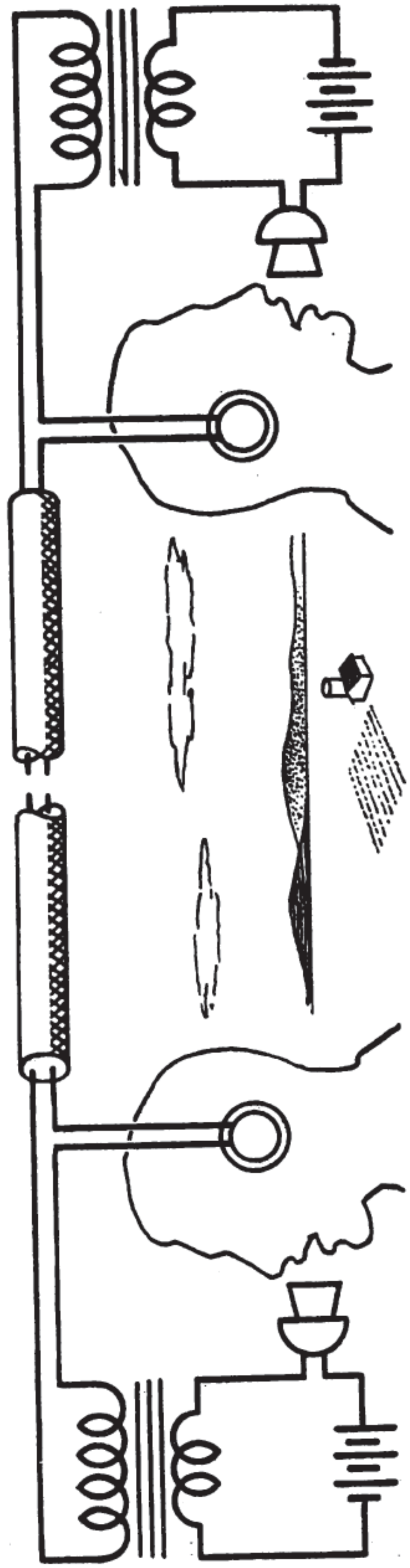


Figure 175.—Local battery telephone system.

requires AUDIO FREQUENCY AMPLIFIERS, known also as REPEATERS. Vacuum tubes are used as audio amplifiers.

A VACUUM TUBE

In a vacuum tube, you find a filament heated to incandescence by current flow from a battery or another suitable voltage supply. The incandescent filament emits electrons. You use a B-battery to apply a POSITIVE potential to a metal electrode, the PLATE, which therefore draws a stream of electrons from the filament. This stream of electrons, of course, is an electric CUR-

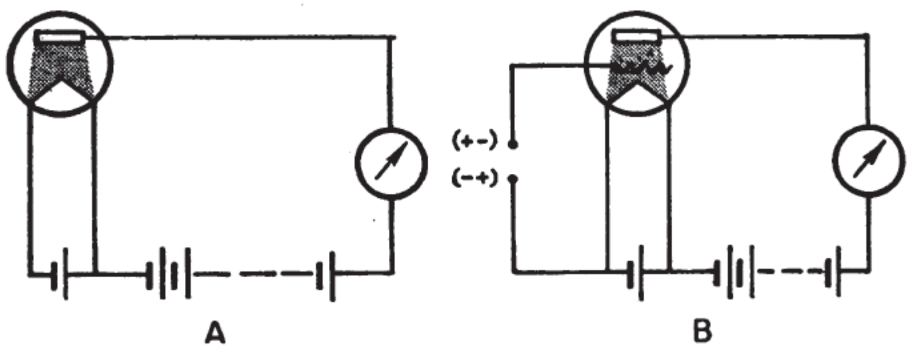


Figure 176.—Operation of simple vacuum tube.

RENT. It is referred to as the PLATE CURRENT. If the voltage applied to the filament and the voltage supplied to the plate are both constant, the plate current is a STEADY, DIRECT current, as you see in (*A*) of figure 176.

Ah, but wait! In (*B*) of figure 176, you have placed a GRID, a meshlike metallic structure, between the filament and the plate. Moving electrons of plate current pass through the grid on the way to the plate. If you place a positive charge on the grid, you increase the number and velocity of the electrons attracted from the filament. Some of these electrons may flow merely to the grid itself, but, because of the

increase in velocity, a greater percentage of them slip through the grid and reach the plate. The result is an increase in plate current whenever the grid is made positive. Now apply a negative charge to the grid, which then REPELS the electrons forming the plate current. Hence the plate current is reduced. The grid is closer to the filament than is the plate. So a charge on the grid has a greater effect on plate current than does a charge on the plate. In this way,

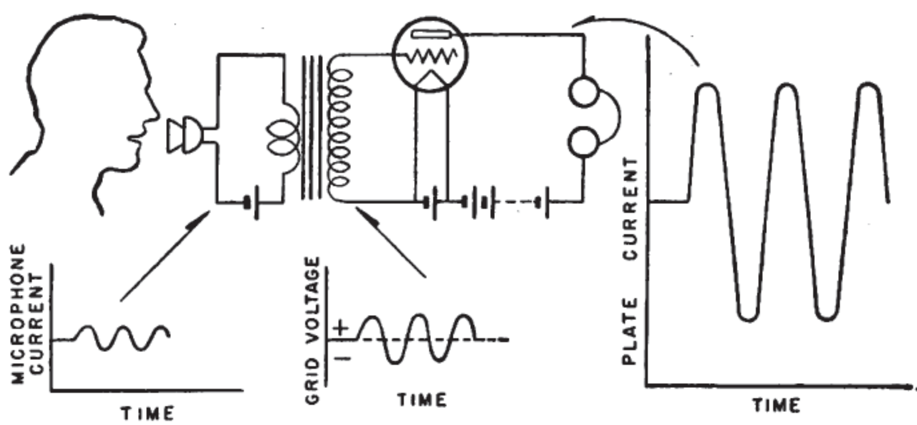


Figure 177.—Single stage audio amplifier.

the grid acts like a valve in increasing or retarding the plate current.

In figure 177, you have a simple telephone circuit connected at the grid circuit of a vacuum tube. Sound waves striking the diaphragm change the resistance of the primary circuit and cause the current in this circuit to pulsate at the same frequency as the diaphragm. The pulsating primary current produces an a-c voltage of the same frequency in the secondary circuit of the transformer. This secondary voltage is applied to the grid circuit of the tube. During the positive half of the cycle, the grid receives a positive charge and the plate current of the tube therefore increases. During the negative half of the cycle, the grid is negatively charged

and the plate current decreases. So the plate current of the tube increases and decreases at the same rate as the original vibration frequency of the microphone.

Connect a telephone receiver in series with a plate, and the pulsating plate current will cause the diaphragm of the receiver to vibrate at the same frequency. Thus the sound striking the microphone is reproduced at the diaphragm of the receiver. The electrical energy used to pro-

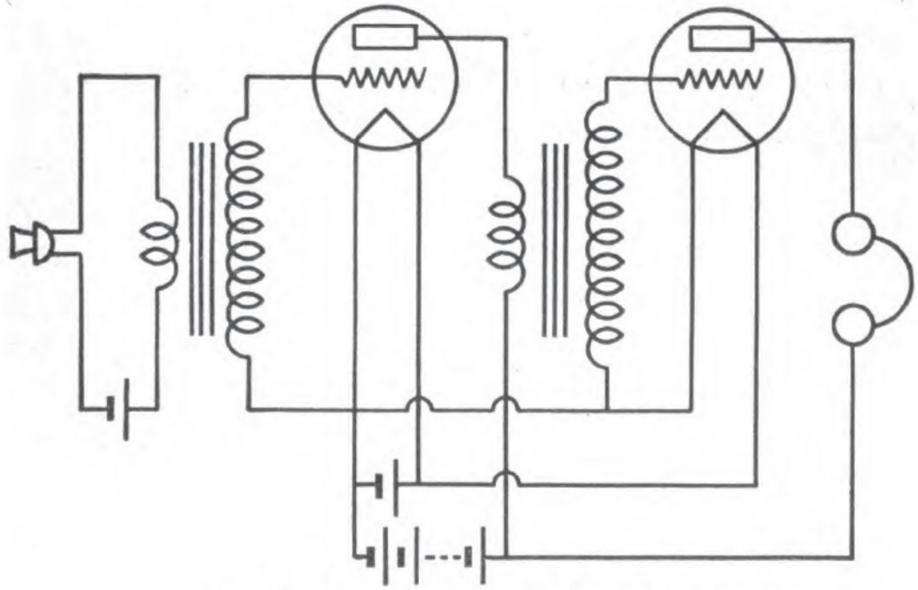


Figure 178.—Two-stage audio amplifier.

duce this motion of the receiver diaphragm is obtained from the B-battery and NOT from the microphone input circuit. Hence the tube really functions as an electrical relay.

The intensity of sound is dependent on current VARIATIONS, or changes, and NOT on the absolute value of the current. The sound produced at the receiver diaphragm will have a greater intensity than the sound at the microphone because the PLATE CURRENT VARIATIONS are much greater than current variations in the microphone circuit. Thus the tube amplifies the original sound. Be-

cause this amplification is at audio frequencies, the circuit is known as an AUDIO FREQUENCY AMPLIFIER.

If the volume obtained at the output of one tube is insufficient, a greater amplification may be developed by feeding this output into the grid of a second tube. You see the diagram of such a circuit in figure 178. In this set-up, a transformer replaces the headphones. The pulsating d. c. in the primary circuit of the transformer produces an alternating voltage in the secondary circuit. The frequency of the secondary voltage is precisely the same as the frequency of the secondary voltage in the microphone transformer. HOWEVER, the voltage output of the second transformer is greater than the voltage output of the microphone transformer. This greatly increased voltage acts on the grid of the second tube to produce variations in the plate current much greater than the variations in the plate circuit of the first tube.

How Well Do You Know—

FUNDAMENTALS OF ELECTRICITY

QUIZ

CHAPTER 1

WHAT IS ELECTRICITY?

1. If a substance has a positive charge, does that mean protons have been added to it?
2. Explain the importance of "grounding" a Leyden jar to give a strong negative charge to—
   (*a*) the outer foil.
   (*b*) the inner foil.

CHAPTER 2

ELECTRICAL CURRENT

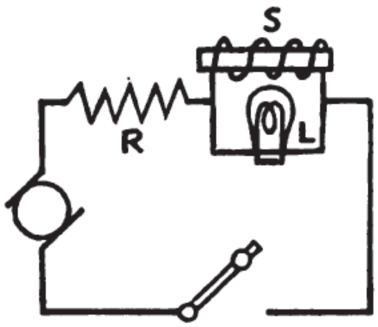
1. What is the difference between a. c. and pulsating d. c.?
2. If there is a difference in electrical level, or pressure, between two points on a conductor—
   (*a*) What is said to flow?
   (*b*) In which direction?
   (*c*) What actually moves?
   (*d*) In which direction?
   (*e*) What is another name for the electrical level or pressure?

CHAPTER 3

ELEMENTARY ELECTRICAL CIRCUITS

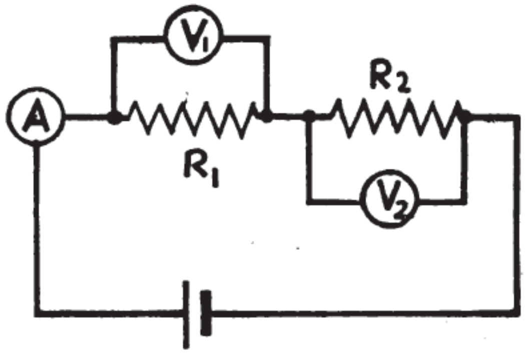
1. In Circuit I (p. 244) how are the following connected?
   (*a*) *L* (Light) with *S* (Solenoid).
   (*b*) *R* with *L* and *S* as a group.

2. In Circuit II (below) how are the following connected?
   (*a*) Ammeter with resistances.
   (*b*) Voltmeters with their resistances.
   (*c*) Resistances with each other.
   (*d*) Ammeter with R_2 and V_2 as a group.



I

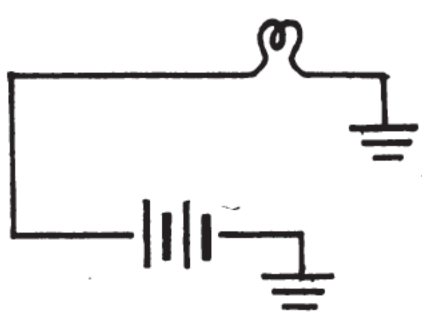
Circuit I.



II

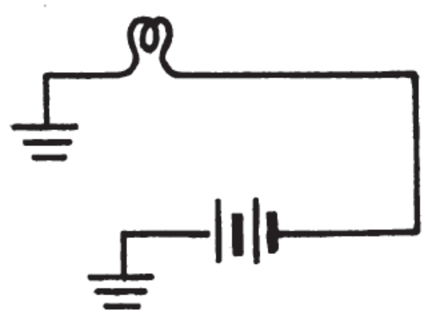
Circuit II.

3. In which of these circuits does the ground act as a
   (*a*) feed wire?
   (*b*) return wire?



I

Circuit I.



II

Circuit II.

CHAPTER 4

OHM'S LAW

1. The voltmeter reading is 6; the ammeter reading is 2. What would the ohmmeter reading be?
2. What are two ways of doubling the strength of any current?

CHAPTER 5

ELECTRICAL MEASUREMENTS

1. Explain why a d-c ammeter may not be connected in parallel with a load, but may be connected in parallel with a shunt.
2. Measuring a circuit current of 300 amperes with a 100-ampere ammeter—
   (*a*) What is the minimum capacity shunt you would need?
   (*b*) At maximum circuit current, what would the ammeter read?
   (*c*) When the ammeter reads 60, what would the circuit current be?
3. Why must you know the approximate amperage or voltage in a circuit before you measure it?
4. Which types of measuring instruments can be connected without regard to polarity?
5. What are two uses of an ohmmeter?

CHAPTER 6

ELECTRICAL CHARACTERISTICS OF PARALLEL AND SERIES CIRCUITS

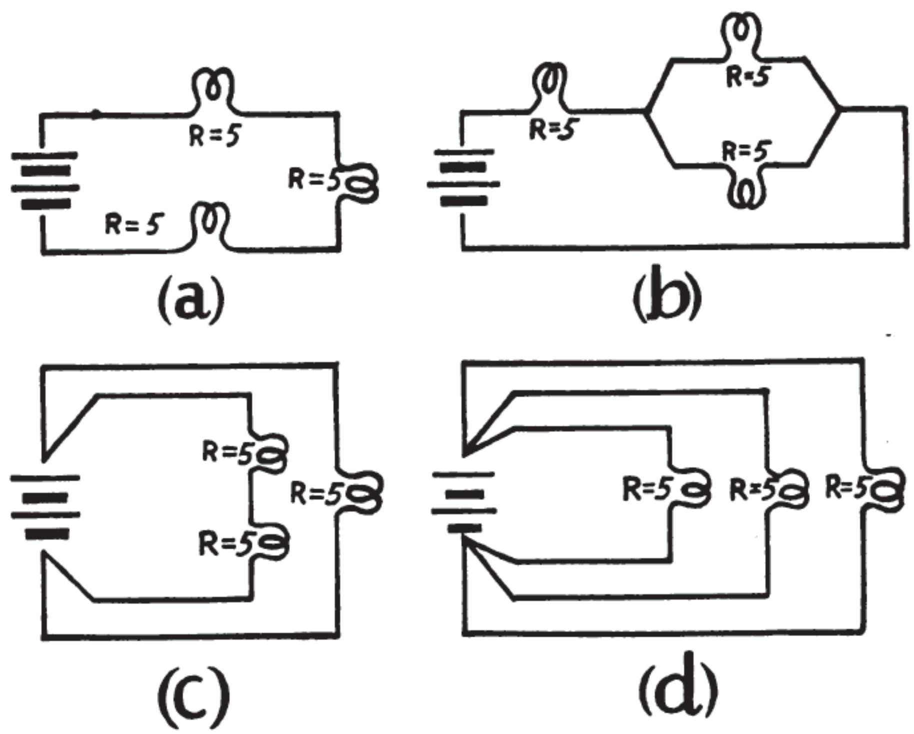
1. Two resistors of 6 ohms and 24 ohms are connected in series. Three resistors of 3, 9, and 18 ohms are connected in series with each other and, as a group, in parallel with the first group. Voltage across the circuit is 180 volts. Calculate: (*a*) Circuit resistance. (*b*) Circuit current. (*c*) Voltage across each resistor. (*d*) Current across each resistor.
2. Two resistors of 6 ohms and 24 ohms are connected in parallel. Three resistors of 3, 9 and 18 ohms are connected in parallel with each other and, as a group, in series with the first group. Circuit current is 10 amperes. Calculate: (*a*) Circuit resistance. (*b*) Circuit voltage. (*c*) Voltage across each group. (*d*) Current through each resistor.

3. Two resistors of 2 ohms and 3 ohms are connected in parallel with each other and, as a group, in series with a resistor of unknown value. Circuit resistance is 6 ohms when circuit voltage is 10 volts. Calculate: (*a*) Resistance across the parallel branch. (*b*) Resistance across the resistor of unknown value. (*c*) Voltage drop across the parallel branch. (*d*) Voltage drop across the resistor of unknown value.

CHAPTER 7

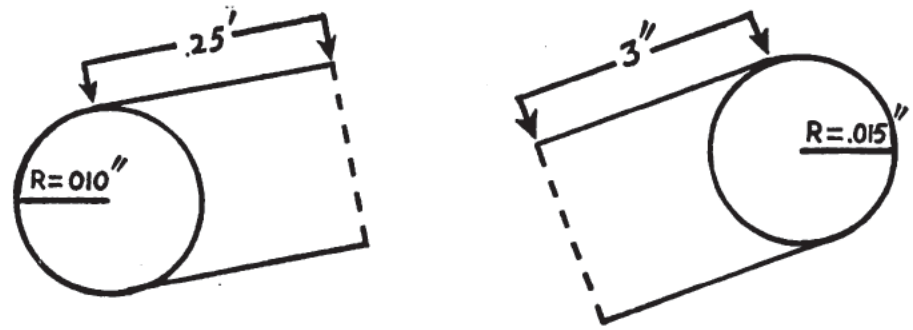
CIRCUIT RESISTANCE

1. What is the circuit resistance in each of these circuits?



2. (*a*) Under what circumstances is the material out of which connecting wires are made, an important factor in circuit resistance?
(*b*) What are three other factors which determine the resistance of connecting wires?

3. (*a*) If both *A* and *B* in this illustration are made of the same material, which is the better conductor?
(b) Calculate the C. S. A. of each conductor, in circular mils.



(A) (B)

CHAPTER 8

CIRCUIT FAULTS

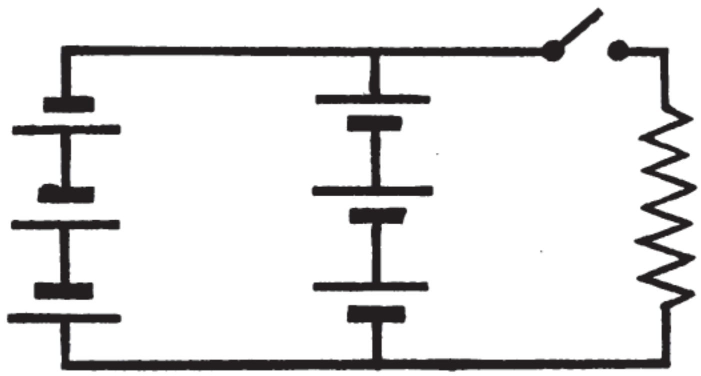
1. How is a loose connection dangerous in—
   (*a*) An airplane?
   (*b*) Any high voltage circuit?
2. (*a*) Against what faults do fuses and thermal circuit breakers protect circuits?
   (*b*) Why must you know the approximate current limit of a circuit in order to use a fuse or a thermal circuit breaker effectively?
3. Explain why you are inviting trouble when you let insulation get oily or greasy.

CHAPTER 9

CELLS AND BATTERIES

1. (*a*) What is the chief difference between primary and secondary cells?
   (*b*) What do they have in common?
2. Do storage batteries have primary or secondary cells?
3. What have E_c, IR, R_i E_t and cell size got to do with how bright a light your flashlight gives?

4. (*a*) What is wrong with the connections of these cells? (*b*) What would happen if you closed the switch? (*c*) If the cells were properly connected, how could you build the voltage up to 12 and the current up to 90? (Assume for this problem that there is no load resistance.)



E_c 1.5 volts
I_m 30 amperes

5. Ten dry cells, each having an emf of 1.5 volts and a resistance of 0.06 ohm, are connected first in series and then in parallel. What is (*a*) the total emf available, and (*b*) the total internal resistance of the cells for each method of connection?
6. An electrical device having a resistance of 1 ohm is connected to 24 cells arranged in 6 banks in parallel, each bank made up of 4 cells in series. Each cell has an emf of 2 volts and an internal resistance of 0.3 ohm. Calculate: (*a*) Total emf. (*b*) Total internal resistance. (*c*) Current through the device.
7. A bell circuit is operated by 3 dry cells in series. Each cell has an emf of 1.5 volts, and an internal resistance of 0.4 ohm. The bell's resistance, including the line, is 12 ohms. Calculate: (*a*) Total emf. (*b*) Total internal resistance. (*c*) Current through the bell.
8. How much current would 20 cells in series, each having an emf of 2 volts and an internal resistance of 0.1 ohm, send through 3 resistances of 20 ohms, 30 ohms, and 60 ohms connected in parallel?

9. (*a*) How can you tell when you have enough electrolyte in your hydrometer for an accurate reading?
(*b*) Just where do you read the hydrometer?
(*c*) A reading of 1218 at 95° F. is comparable to a reading of ______ at 77° F.
10. (*a*) What does "state of charge" mean?
(*b*) Why has a discharged storage battery a lower state of charge?
(*c*) Why should a fully discharged battery be recharged immediately?
(*d*) Why must generator and battery be connected positive-to-positive terminal and negative-to-negative terminal, in order to recharge the battery?
11. (*a*) What does the Tungar rectifier bulb rectify?
(*b*) In Fig. 92, with the switch closed, what would happen if you placed the selector switch so as to get a voltage of 10 across *R–S*?
12. What would you think about the condition of an average storage battery under these circumstances?

(*a*)	Hydrometer reading at 12:00 (noon)	1.285 (77° F.)
	Hydrometer reading at 12:30	1.285 (77° F.)
	Hydrometer reading at 1:00	1.285 (77° F.)

(*b*) Distilled water added to electrolyte at 4:10 p. m.; hydrometer reading at 4:20=1.140.
(*c*) Same as (*a*)—and—at 1:30, Weston Cell Tester indicates 300 amperes for 30 seconds, with terminal voltage at end of 30 seconds=1.50.
13. (*a*) On a high-amperage discharge test, why wouldn't you expect to get the same discharge reading from a very small storage battery as a larger battery?
(*b*) How would you determine the standard reading for a small battery?
14. A battery able to supply current at the rate of 5 amperes for 50 hours is said to have how much electrical capacity? How about a battery which can last 100 hours on a circuit requiring 2½ amperes?
15. Why are batteries connected in parallel with each other, in a constant potential charging system?

16. (*a*) Should you test a storage battery more often in January or July? Why?
(*b*) What is the maximum allowable interval between tests in any weather?
17. What are four things you must consider in determining how strong a current to use in charging a battery?
18. (*a*) What is the symptom of battery corrosion?
(*b*) What is one way to prevent it?
(*c*) What is the cure?
19. Give 3 maintenance rules, other than those mentioned in the above questions, which protect
(*a*) Your own safety.
(*b*) The battery.
20. (*a*) If a storage battery's no-load voltage is 6, how many cells would you expect it to have?
(*b*) What is the no-load voltage of most airplane storage batteries?

CHAPTER 10

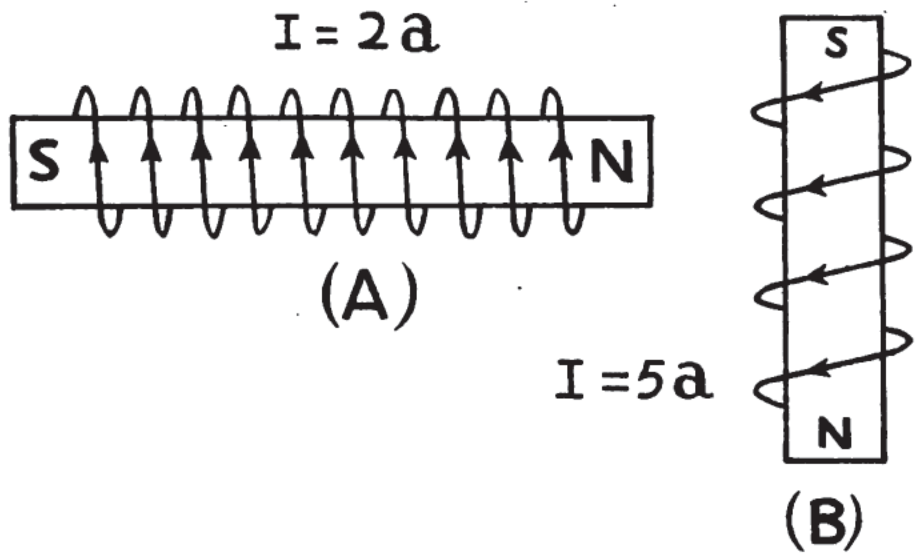
MAGNETISM

1. (*a*) What law of magnetism corresponds to the electrical law that like charges repel and unlike charges attract each other?
(b) On the basis of your answer to (*a*), how is it that the (*N*) pole of a magnetic compass needle in the Northern Hemisphere will tilt downward?
2. (*a*) Why must navigators know their angles of declination?
(*b*) Does the compass deviation chart show these angles?
3. What is the difference between isogonic and agonic lines?
4. In which general direction would you expect isoclinic lines to run: *N–S* or *E–W*?
5. How is molecular alinement different in (*a*) Unmagnetized and magnetized materials? (*b*) Temporary and permanent magnets?
6. In which direction do lines of magnetic force move?

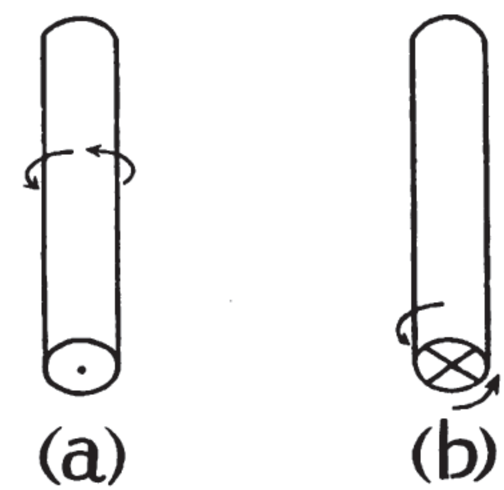
CHAPTER 11

ELECTROMAGNETISM

1. In these conductors, is the direction of magnetic flux correctly indicated?



2. (*a*) Are these solenoids or electromagnets?
   (*b*) Are the poles labelled correctly?
   (c) How do (*a*) and (*b*) compare as to ampere-turns?



CHAPTER 12

GENERATORS

1. Upon what factors do the following depend?
   (*a*) Direction of induced emf.
   (*b*) Strength of induced emf.

2. Explain the difference between the relation of slip and split rings to generator brushes.
3. If a 6-pole generator has a frequency of 195 cycles
   (*a*) How many cycles does a loop go through during one complete rotation?
   (*b*) How many times does the current in the loop reverse direction during one rotation?
   (*c*) What is the speed of rotation?
4. Is "armature" the same as "rotor"?
5. In the "shunt" generator what is shunted, and why?
6. In the voltage regulator circuit—
   (*a*) What releases the spring tension?
   (*b*) What effect does releasing the spring tension have on the magnetic flux about the armature?
   (*c*) What effect does the change in magnetic flux have on the generator's voltage?
   (*d*) What is the over-all effect of (*a*), (*b*), and (*c*) on the aircraft electrical system?
7. What is the function of the reverse current cut-out relay?

CHAPTER 13

D–C MOTORS

1. In a motor with a one-loop armature—
   (*a*) What causes the armature to move?
   (*b*) How far would the armature move without commutator segments?
   (*c*) What is the function of the commutator segments?
   (*d*) If the loop rotates in a clockwise direction, how can you make it rotate counter-clockwise?
2. Why does a commercial motor armature always have more than one loop?
3. (*a*) Why is difference voltage greater when a motor runs at low speed?
   (*b*) Does the motor receive more current at high or low speed? Why?

4. In an airplane starter motor—

(*a*) How are field windings connected with respect to the armature?

(*b*) Must the field windings be connected in series with respect to each other?

CHAPTER 14

ELECTROMAGNETIC INDUCTION

1. (*a*) Can a transformer be made to operate on d. c.?

(*b*) Why is a. c. generally used for transformers?

2. If an auto-transformer with 100 turns of wire has a total voltage of 600, and you use 20 turns for the secondary circuit—

(*a*) Is it a step-up or step-down transformer?

(*b*) What voltage will be induced in the secondary circuit?

3. (*a*) On what current do ignition and induction coils operate?

(*b*) In the ignition coil, what produces the "change" in current necessary for transformer action?

(*c*) What is the effect of the transformer action?

(*d*) In the induction coil, what produces the necessary "change" in current?

(e) What kind of current is induced in the secondary circuit of the induction coil transformer?

CHAPTER 15

INDUCTANCE AND CAPACITANCE

1. (*a*) When counter emf is developed in a coil as a result of the application of voltage to that coil, what is the phenomenon called?

(*b*) When counter emf is developed in a coil as a result of the application of voltage in a nearby coil, what is the phenomenon called?

(c) Are the effects of the counter emf different in (a) and (b)? If so, how?

2. (a) What is the term applied to the ability of a condenser to store electricity?
   (b) What are three factors on which it depends?
   (c) What is its unit of measurement?
3. (a) Which will oppose the flow of current at the instant a circuit is made: inductance or capacitance?
   (b) Which will oppose the flow of current at the instant the circuit is broken?
4. Is the effect of inductance more marked at the make or break of the circuit?
5. What kind of condenser—
   (a) Has stator and rotor plates?
   (b) May have either wet or dry dielectric?
   (c) Has low capacitance in spite of its high voltage rating.
6. How would you combine condensers if you needed—
   (a) More capacitance but no higher voltage rating?
   (b) Higher voltage rating but no more capacitance?

CHAPTER 16

SOUND

1. (a) In the case of sound, what is wavelength?
   (b) What is amplitude?
   (c) What characteristic of sound depends upon amplitude?
2. Middle C has a frequency of 256. What would its wavelength in air be at 92° F. if it is 4.378 at 60° F.?
3. (a) How does a transformer improve the simple telephone?
   (b) How can you effect even more improvement, of the same type?
   (c) In a telephone circuit containing the above improvements, how many times is the current changed from a. c. to d. c. or vice versa?

ANSWERS TO QUIZ

CHAPTER 1

WHAT IS ELECTRICITY?

1. No; Electrons have been removed.
2. (*a*) The ground provides a SOURCE OF ELECTRONS which can be piled up on the outer foil by the attraction of the positively charged inner foil.
   (*b*) The ground provides an AVENUE OF ESCAPE for excess electrons (on the outer foil) which would otherwise repel electrons from the inner foil and prevent their concentration there.

CHAPTER 2

ELECTRICAL CURRENT

1. A. C. flows alternately in one direction and then in the opposite direction; pulsating d. c. flows in one direction, but periodically waxes and wanes in strength.
2. (*a*) Current.
   (*b*) Positive to negative.
   (*c*) Free electrons.
   (*d*) Negative to positive.
   (*e*) Voltage (also: electromotive force; potential).

CHAPTER 3

ELEMENTARY ELECTRICAL CIRCUITS

1. (*a*) Parallel.
   (*b*) Series.
2. (*a*) Series.
   (*b*) Parallel.
   (*c*) Series.
   (*d*) Series.
3. (*a*) II.
   (*b*) I.

CHAPTER 4

OHM'S LAW

1. 3.
2. Double the voltage OR cut the resistance in half.

CHAPTER 5

ELECTRICAL MEASUREMENTS

1. A d-c AMMETER connected in parallel with a load would offer a path of such low resistance, in comparison to the *R* of the load, that a high circuit current would flow through the ammeter, overloading and breaking that instrument.

   A d-c AMMETER SHUNT is so constructed as to offer even less resistance than the ammeter, so that when connected in parallel with it the ammeter shunt will carry most of the circuit current.
2. (*a*) 200 amperes.
   (*b*) 100 amperes.
   (*c*) 180 amperes.
3. Because all ammeters and voltmeters are made to measure within limits marked on their scales. Excessive *I* or *E* may damage the instrument's pointer or moving coil.
4. Ohmmeter; zero-center ammeter.
5. Measure *R* directly; locate circuit faults.

CHAPTER 6

ELECTRICAL CHARACTERISTICS OF PARALLEL AND SERIES CIRCUITS

1. (*a*) 15 ohms.
   (*b*) 12 amperes.
   (*c*) 6-ohm resistor: 36 volts.
   24-ohm resistor: 144 volts.
   3-ohm resistor: 18 volts.
   9-ohm resistor: 54 volts.
   18-ohm resistor: 108 volts.
   (*d*) 6 amperes.

2. (*a*) 6.8 ohms.
   (*b*) 68 volts.
   (*c*) First group: 48 volts.
   Second group: 20 volts.
   (*d*) 6-ohm resistor: 8 amperes.
   24-ohm resistor: 2 amperes.
   3-ohm resistor: 6 amperes.
   9-ohm resistor: 3 amperes.
   18-ohm resistor: 1 ampere.
3. (*a*) 1.2 ohms.
   (*b*) 4.8 ohms.
   (*c*) 2.0 volts.
   (*d*) 8.0 volts.

CHAPTER 7

CIRCUIT RESISTANCE

1. (*a*) 15.0.
   (*b*) 7.5.
   (*c*) 3.3.
   (*d*) 1.7.
2. (*a*) When load resistance is low and the resistance of connecting wires is a significant part of total circuit resistance.
   (b) Length.
   C. S. A.
   Temperature.
3. (*a*) *B*.
   (*b*) A=400 circular mils.
   B=900 circular mils.

CHAPTER 8

CIRCUIT FAULTS

1. (*a*) Vibration may break-make the circuit at the loose connection and cause an unsteady flow of current to an important electrical unit.
   (*b*) Current will arc, deteriorating the connection if not starting a fire.

2. (*a*) Short circuits and overloading.

   (*b*) The protective value of these devices depends upon their breaking the circuit when the current exceeds a certain maximum.

3. Oil and grease, among other things, cause deterioration of insulation. Unprotected by insulation, conductors may make contact with each other or with grounding material.

CHAPTER 9

CELLS AND BATTERIES

1. (*a*) A primary cell must be discarded after it has discharged, because its plates are consumed; a secondary cell can be recharged and used again.

   (*b*) They are both sources of voltage; both contain electrodes and electrolyte.

2. Secondary.

3. The more E_c a cell "drops" (IR) forcing current through its own resistance (R_i), the less it has left (E_t) for load resistance. Thus the higher the R_i, the less current delivered through the load resistance and the dimmer the flashlight.

   Cell size is important because larger cells generally have less R_i.

4. (*a*) To be properly connected in parallel, all the cells' positive terminals should be connected to one conductor and all their negative terminals to the other conductor.

   (*b*) Voltage of all cells would act in the same direction to send maximum current through the complete 6-cell circuit; i. e., short circuit the cells.

   (*c*) Add 5 cells to each bank for voltage; add another 8-cell bank for current.

5. Series: (*a*) 15.0 volts.

   (*b*) 0.6 ohms.

   Parallel: (*a*) 1.5 volts.

   (*b*) 0.006 ohms.

6. (*a*) 8.0 volts.
   (*b*) 0.2 ohm.
   (*c*) 6.67 amperes.
7. (*a*) 4.5 volts.
   (*b*) 1.2 ohms.
   (*c*) 0.341 ampere.
8. 3.33 amperes.
9. (*a*) When you release the hydrometer bulb completely and the float floats free.
   (*b*) On the float stem, precisely at the surface of the electrolyte.
   (*c*) 1210.
10. (*a*) Electrical capacity.
   (*b*) During discharge, the acid from the electrolyte combines with the electrodes (plates), coating them with sulfate which reduces the effective plate area and the electrical capacity.
   (*c*) To prevent the sulfate from hardening on the plates and permanently reducing electrical capacity.
   (*d*) Because a direct current must be sent through the battery in a direction opposite to the direction of current flow during battery discharge, in order to restore plates and electrolyte to their original condition.
11. (*a*) The bulb rectifies alternating to direct current, in a battery charging circuit, by permitting it to flow in only one direction.
   (*b*) The voltage of 12 across *K–G* would overcome the voltage of 10 across *M–N* and tend to send a current through the charging circuit from the discharging batteries. Actually no current would flow, since the rectifier bulb would not permit current in that direction.
12. (*a*) Battery is fully charged.
   (b) Battery is not fully charged, but probably no more than normally discharged. (Reading immediately after addition of distilled water will indicate state of charge below actual state.)
   (c) Battery is fully charged, but cell tested is faulty.
13. (*a*) Because the R_i of small batteries is greater than that of larger units and therefore small batteries cannot

be expected to give the same current value as larger batteries over a given period.

(*b*) From the manufacturer's specifications, or the performance of a similar battery in good condition.

14. Both batteries would be rated at 250 ampere-hours.
15. So that each battery on charge may receive current in proportion to its individual needs, i. e., its state of charge, independent of the amount of current going to the other batteries.
16. (*a*) January; because a discharged battery freezes easily.

    (*b*) One week.
17. Normal rate specified on battery name plate.

    Time available for charging.

    Temperature (110° F. maximum).

    Cell gassing (means charging rate must be reduced).
18. (*a*) Greenish-white formation on battery terminals.

    (b) Keep acid spray off top surface of a battery during charging, by keeping vent plugs on.

    (*c*) Use wire brush thoroughly on affected parts; apply strong solution of baking soda to neutralize any acid not removed by brushing; wash battery with fresh water; dry with compressed air or a cloth; coat the terminals with petrolatum or melted paraffin.
19. (*a*) Never use a match when you check electrolyte level.

    See that room used for recharging is well ventilated.

    Never disconnect leads to a battery on charge.

    (*b*) Maintain electrolyte 3/8″ or more above top of separators.

    Do not draw heavy discharge currents for long periods.

    Never subject battery to strong vibration or rough handling.
20. (*a*) 3 cells.

    (*b*) 12 volts.

CHAPTER 10

MAGNETISM

1. (*a*) Like magnetic poles repel and unlike poles attract each other.

(*b*) In the Northern Hemisphere, the (*N*) pole of the compass is attracted by and so tilts downward toward the unlike magnetic pole of the earth called the earth's (*N*) magnetic pole because of its proximity to the (*N*) geographic pole, but actually the earth's (*S*) magnetic pole.

2. (*a*) Because the magnetic compass points toward the magnetic pole, which is actually some distance from the geographic pole. Except when the navigator's position happens to be directly in line with both these poles, he must know the ANGLE between a line to the magnetic pole and a line to the geographic pole, in order to get his true bearings.

   (*b*) No. This charts the necessary corrections for an airplane compass' errors caused by the influence of other magnetic materials in the airplane.
3. Points on the earth's surface at which ANGLES OF DECLINATION ARE EQUAL are connected by ISOGONIC LINES. Points at which there is ZERO DECLINATION (i. e., a magnetic compass will point true North) are connected by AGONIC LINES.
4. E–W.
5. (*a*) UNMAGNETIZED MATERIALS contain a jumble of individual molecular magnets. In MAGNETIZED MATERIALS the molecular magnets line up with all their (*N*) poles facing one way and all (*S*) poles another.

   (*b*) In TEMPORARY MAGNETS a smaller proportion of the molecules has been lined up, than in a PERMANENT MAGNET. Temporary magnetism is thus more easily induced AND destroyed.
6. North pole to South pole.

CHAPTER 11

ELECTROMAGNETISM

1. (*a*) Yes.

   (*b*) No.
2. *A* and *B* are both solenoids AND electromagnets.

   (*b*) *A*—No.

   B—Yes.

   (*c*) They are equal, each having 20 ampere-turns.

CHAPTER 12

GENERATORS

1. (*a*) Direction of conductor's movement through the magnetic field; and direction of magnetic flux.
   (*b*) Number of lines of force cut per second; i. e., conductor's speed and magnetic field's strength.
2. Each SLIP RING maintains contact with the same brush throughout the cycle; as current alternates (changes direction) within the armature loop it also alternates through each slip ring and brush and consequently through the external circuit. Each segment of the SPLIT RING touches alternate brushes as the loop rotates, so that one brush always contacts the side of the loop moving downward and the other always contacts the side moving upward. The external circuit receives direct current from the brushes.
3. (*a*) 3 cycles.
   (*b*) 3 times.
   (*c*) 3,900 rpm.
4. No. The armature may be rotor or stator.
5. The field windings are shunted across the armature circuit, so that part of the output current will be diverted to excite the field.
6. (*a*) Magnetic attraction of the solenoid for the iron core.
   (*b*) The carbon wafers separate, increasing field R, cutting down field current and, therefore, magnetic flux.
   (*c*) As magnetic flux decreases, less emf is induced in the generator.
   (*d*) It limits the amount of voltage, and therefore the current, which the generator can deliver.
7. To prevent the battery from discharging into the generator when voltage falls below that of the battery.

CHAPTER 13

D-C MOTORS

1. (a) The repulsion of field flux and conductor flux in the same direction.

(*b*) One half-rotation, to the point where field flux and conductor flux would be in opposite directions.

(*c*) To preserve the relation between direction of field flux and conductor flux, by reversing the current in the armature loop every half-rotation, so that rotation will be continuous.

(*d*) Interchange the field connections at the brushes.

2. The more loops in the armature, the greater and the more uniform the turning force.
3. (*a*) Because difference voltage is the difference between counter emf and impressed voltage, and the amount of counter emf depends upon the number of lines of magnetic force cut per second. More lines are cut at high speed.

   (*b*) Low speed; because the amount of current delivered to the motor depends upon difference voltage.
4. (*a*) In series.

   (*b*) No. They may be connected in series, parallel, or series-parallel with respect to each other.

CHAPTER 14

ELECTROMAGNETIC INDUCTION

1. (*a*) Yes.

   (*b*) Because emf is induced by CHANGE in magnetic flux, accompanying CHANGE in current. On d. c., the current "changes" at the moment the circuit makes or breaks. On a. c., voltage is continually induced in the secondary circuit as the current reversals in the primary circuit alternately build up and collapse its magnetic field.
2. (*a*) Step-down.

   (*b*) 120 volts.
3. (*a*) D. C.

   (*b*) Breaker points in the primary circuit distributor.

   (*c*) To build up in the secondary winding a voltage so high that a spark will jump the gap.

   (*d*) Interrupter circuit in the primary circuit.

   (*e*) Irregular a. c.

CHAPTER 15

INDUCTANCE AND CAPACITANCE

1. (*a*) Inductance.
   (*b*) Mutual induction, or magnetic coupling.
   (*c*) Its effects are the same within the coils in which it is induced.
2. (*a*) Capacitance.
   (*b*) Area and proximity of plates; and dielectric material.
   (*c*) Farad.
3. (*a*) Inductance.
   (*b*) Both inductance and capacitance.
4. Break.
5. (*a*) Variable.
   (*b*) Electrolytic.
   (*c*) Mica.
6. (*a*) Parallel connection.
   (*b*) Series connection.

CHAPTER 16

SOUND

1. (*a*) The distance between two successive points of maximum condensation.
   (*b*) One-half the distance through which the vibrating source of the sound wave moves.
   (*c*) Intensity (loudness).
2. 4.51.
3. (*a*) It extends the range of communication by stepping up the voltage produced in the microphone.
   (*b*) Add a vacuum tube audio frequency amplifier.
   (*c*) Twice: (pulsating) d. c. to a. c. in the secondary winding of the transmitter transformer; and a. c. to (pulsating) d. c. in the vacuum tube.

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